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# THE SHOCK AND VIBRATION DIGEST

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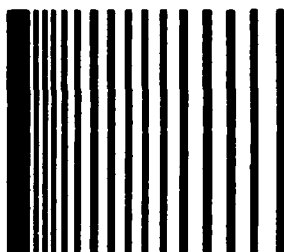
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## THE SHOCK AND VIBRATION DIGEST

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# SVIC NOTES

## Environmental Data

The Shock and Vibration Information Center receives many requests for data on vibration, acoustic and shock environments. Most requests relate to specific vehicle types such as fighter aircraft, helicopters, launch vehicles, missiles, ships or rail vehicles. We can usually answer the request by referring to one or more articles published in our own Shock and Vibration Bulletin or in a similar open literature publication.

Many times, however, the exact data needed cannot be found in an open publication. In this editorial, I would like to point out why proper environmental data are sometimes hard to find and what can possibly be done to make data more readily available.

Proper environmental data are hard to find for several reasons. measurement locations don't match, the data are displayed in an unsuitable format, the data are in a company proprietary report, the data was never reduced and published and was eventually lost.

The first problem is inappropriate measurement location. It is a fortunate event if you find that previous researchers have picked the exact location, transducer type, and measurement direction (X, Y or Z) that is of interest to you.

The second problem is the data reduction format. In shock data, for instance, you may want time history, peak g's acceleration, velocity, displacement or shock response spectra. If the previous researcher integrated the acceleration to obtain the velocity there probably was an optional filtering frequency chosen when processing the data. In calculating a shock spectrum there is an option to choose one or more Q values. All of these options decrease the likelihood that the previous researchers picked the format you want and hence the previous measurements are of no use to you.

The third problem is the proprietary status of many company reports. Vehicle manufacturers collect a lot of environmental data but the reasons for making the measurements are the company's own business. Also, what they do with the data and whether or not they publish any or all of it is their own business. Consequently much of it remains in internal company reports.

The final factors to consider are the costs and logistics associated with acquiring, reducing and storing environmental data. Due to budget and cost constraints more data are taken than are ever reduced and more data are reduced than are ever published in a report. The half-life of un-reduced data and tapes isn't more than one or two years. Data tapes get misplaced and information on the experimental conditions gets lost. Personnel changes, paperwork reduction acts and record clean-out campaigns cause data to be mislabeled, misplaced, erased or just thrown away. And in reality, there is no financial incentive for an organization to keep all their measured data archived for 10 to 15 years waiting for someone to develop a need for the information.

Some things can be done to make more data available. More control should be exercised by management during the planning period, before any data are taken; they should establish exactly why data are being taken and how the data are to be reduced before any recorders are turned on. Taking data and then not using it is a waste of time and money. More papers containing environmental data should be presented at open meetings and symposia. Critical or irreplaceable data should be identified and funds made available to either maintain the data in centralized data banks or reduce the data to an inexpensive, copyable format. Standardized formats for data reduction and presentation should be more widely used.

And finally, more attempts should be made to use the newer, more powerful data storage and retrieval technology such as magnetic disks, optical disks and laser disks. It is now possible to inexpensively reduce, copy and distribute all of the test data for a particular vehicle test series on a small, rugged disk which can be sent through the mail and played back by someone with appropriate equipment.

If more environmental data were reduced and stored quickly and automatically, then much less of it would be lost.

J. G. S.

# EDITORS RATTLE SPACE

## ON THE DEVELOPMENT OF MACHINE STANDARDS

Last year I wrote about the controversy involved in the selection of overall peak or RMS (true) vibration as an index indicative of machinery condition. This controversy has been in existence among American engineers for over 20 years. In fact it has delayed the adoption of machine vibration standards by the Acoustical Society of America (ASA)/American National Standards Institute (ANSI) until recently. The publication standard ASA 56-1985, **Mechanical Vibration of Large Rotating Machines with Speed Range from 10 to 200 REV/s — Measurement and Evaluation of Vibration Severity in Situ\***, reflects a break in the situation.

ASA 56 utilizes vibration measurements taken on the machine bearing or bearing housing processed to obtain RMS velocity in the 10 to 1000 Hz range. This document has limited usefulness because of the general type of measurement and frequency range. However, I believe it is a step in the right direction. ASA 56 applies to once-per-revolution problems such as mass unbalance and misalignment in rolling element bearing mounted rotors. However, it does apply to certain stiff sleeve bearing machines. Since the vibration severity levels relate to once-per-rev problems there is a problem with the wide operational speed range. Bearing frequencies of low speed machines -- up to 3600 RPM -- will fall in the 1000 Hz frequency range of the meter processing the data. This may cause problems in severity interpretation. It appears that severity tables reflecting two ranges of the RMS index would be in order -- one for once-per-rev problems and the other for higher frequency phenomena such as bearing and/or gear defects. In addition, two speed ranges with appropriate adjustment in frequency ranges would help to separate these effects.

Although ASA 56 has been in existence as ISO 3945 for over 8 years, results on its use have not been published. Adjustments in frequency ranges and levels given in the severity tables will have to be made after vibration data processed in the manner of ASA 56 have been recorded and compared to machine condition.

The advent of the new class of data recording devices used to obtain, process, and store vibration data provides the opportunity to refine ASA 56. It appears that it would not be difficult to design a discipline program to process data in a manner consistent with this goal; and, yet provide the machine protection sought from the recording of periodic data. Thus in the future better diagnostics would be obtained for all classes of machines and types of faults. ANSI Committee 52-76 have initiated a program to obtain vibration data for development of standards and their associated severity levels. Anyone wishing to cooperate in this program should contact Paul Maedel, chairman of 52-76, or myself at the Vibration Institute.

R.L.E.

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\*Copies of ASA 56 can be obtained from the Standards Secretariat, Acoustical Society of America, 335 East 45th Street, New York, New York 10017.

## FREQUENCY DOMAIN EXPERIMENTAL MODAL ANALYSIS TECHNIQUES

M. Rades\*

**Abstract.** This paper reviews some recent advances in the development of structural modal identification procedures. Only methods concerned with frequency response data in the frequency domain are considered. Emphasis is on the theoretical background of analytical modal characterization techniques. Testing philosophy is also considered.

Interest in estimating modal characteristics from test data has increased in the past several years. Experimental modal analysis (EMA) has become an important part of structural dynamics technology and is now a basic approach in the growing field of computer-aided engineering. Overviews of the latest developments in modal analysis are available [1-6], as is a short review of modal modeling techniques currently in use [7].

Recent advances in EMA have been facilitated by new measurement and computational hardware and easy-to-use software. Dual channel FFT signal analyzers, capable of high-quality frequency response measurements, have been introduced [8], and powerful desktop computers are available [9]. Several dedicated modal analysis systems are commercially available; many companies have designed and implemented computer-based modal testing and analysis systems. They are fast and powerful tools for the acquisition and analysis of vibration data.

EMA has become the most cost-effective method for structural coupling and modification simulation [10, 11], finite element model validation [12, 13], equipment qualification [14], and troubleshooting [15]. Graphic displays of frequency response functions (FRF) and animated mode shapes allow dynamic properties to be interpreted

quickly and sources of vibration problems to be identified.

Currently used data analysis hardware and software is oriented toward the estimation of frequency responses. Most modern modal testing procedures involve multi-frequency structural excitation, digital acquisition of time-series information, reduction to spectra by the FFT, and processing of resulting FRFs to modal parameters by interactive curve-fitting techniques.

Current trends in modal-characterization software are: use of truncated modal models (with additional residual terms), simultaneous ensemble fitting of FRFs obtained from multiple input excitation (in order to utilize the redundant information contained in the FRF matrix), least squares estimation, allowance for high modal density and nonproportional damping, and use of modal confidence factors. The most critical point remains estimation of the optimal number of degrees of freedom (DOF) to be considered (model order estimation).

New topics include rotor dynamics applications [16, 17], test-derived strain modal models [18, 19], use of frequency-dependent modal vectors [20], global fitting methods, use of enhanced FRFs, and curve fitting to partly tuned FRFs.

The information obtained from experiments can be analyzed in the frequency domain or in the time domain. Hybrid methods also exist [21]. Powerful time domain algorithms as the least squares complex exponential (LSCE) [21], Ibrahim time domain (ITD) [22], and polyreference [23] are available commercially in software packages.

Direct time domain processing eliminates leakage errors. Methods that utilize fre-

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quency response measurements are better known. Most are based on FRF theoretical curve fitting, but others use unprocessed input/output data. Impulse responses obtained from the inverse Fourier transform of the FRF are used in the Prony algorithm [24, 25]. Wrap-around error (time domain leakage) can occur when the FFT is used in this process due to the truncated form of FRFs.

A modal model of a structure can be obtained by two approaches: direct modal identification or curve fitting and indirect modal identification or direct system parameter identification. With the first approach a modal model -- including natural frequencies, modal damping, and mode shapes -- is derived directly from measurements. With the second approach the parameters of a physical model -- coefficients of mass, damping, and stiffness matrices -- are estimated and then used to determine a modal model. The major advantage of a modal model over a physical model is that the modal model is condensed.

#### FREQUENCY DOMAIN CURVE FITTING

In the direct modal identification approach, a parametric mathematical expression is assumed for FRFs and fitted to the measured responses by estimating the parameters. Often the fitting process is made in two stages: estimation of natural frequencies and damping and estimation of mode shapes.

**Single-mode algorithms.** Single-degree-of-freedom (SDOF) algorithms perform an independent fit of each resonance peak (or loop) one mode at a time. They are utilized for systems with low modal density and relatively light damping, in troubleshooting applications, or in the second stage of multiple DOF fitting processes for determining mode shape coefficients.

Three algorithms are used in modal analysis systems: quadrature picking, circle fit, and polynomial curve fit. Quadrature picking involves observation of peaks in the imaginary part and zero crossings in the real part of the FRF close to resonance frequency. Data bandwidth and center

frequency are required. Circle fit involves a least squares fitting of a best circle to each resonance loop in a Nyquist plot of the FRF. Polynomial curve fit matches a rational fraction polynomial representation of an SDOF analytical transfer function, evaluated as an FRF, to experimental data by a least squares curve fit. Implementation of these algorithms is interactive.

A noninteractive self-verification method has been suggested [26]. Three comparison ratios for evaluating the fitting quality include the modal spacing ratio-reciprocal of modal density [27], the strength ratio-ratio of FRF peak magnitudes, and the modal resolution ratio-ratio of the curve fit bandwidth to the half-power bandwidth.

**Multi-mode algorithms.** Multi-degree-of-freedom (MDOF) algorithms perform a simultaneous fit of several resonance peaks (or loops) separately for each FRF (one curve at a time). MDOF techniques are utilized for systems with high modal density (overlapping of half-power bandwidths of two adjacent modes) or high damping (resonance loops or peaks not visible in the response plots).

Modal parameters of many modes from a band of measurement data are simultaneously estimated. The number of these modes is usually smaller than the number of structural DOF and much smaller than the number of DOF of the identification model. When the number of modal parameters is smaller than the experimental data available, no exact solution can be found. Optimal values of the modal parameters are found by minimizing the squared error between calculated and experimental data (least squares method). When the model order is greater than the system order, the number of determined modes is greater than the number of structural modes; the extra determined modes are called computational or noise modes. They are readily identified because they cannot be repeatedly obtained by selecting a different set of effective DOF. The concept of modal confidence factor was introduced to sort out the physically meaningful modes [28].

The effect of out-of-band modes is compensated by using either additional residual

terms in the FRF mathematical expression [29] or extra modes in the identification model. Additional modes increase the model order, but residual terms are not global modal properties. It is not possible to predict the residues of a point FRF from those of another point FRF or the transfer FRF corresponding to a pair of points when direct FRFs are measured. Critical views on the use of residuals have been presented [30]. Determination of the number of DOF in the data is critical for most algorithms.

Two alternative analytical forms of the FRF are the partial fraction expansion and the rational fraction form. Curve fitting methods based on the partial fraction expansion of the FRF have been reviewed [31]. The linear least square frequency domain (LLSFD) algorithm is a direct solution method. Optimal mode shape and residual coefficients are calculated from given values of natural frequencies and damping ratios. They are usually defined by a graphical method or by more sophisticated algorithms. The nonlinear least square frequency domain (NLSFD) algorithm is an iterative solution method. Natural frequencies, damping ratios, mode shapes, and residual coefficients are calculated simultaneously. The initial frequency and damping values are optimized by a search procedure. With both methods the number of modes is selected by visual inspection of measured FRFs. The goodness-of-fit check is made synthesizing a FRF with the estimated values of modal parameters and overlaying this function on original test data. Phase errors occur when fitting is based on the modulus of the complex FRF [32].

A new algorithm called the frequency domain prony (FDP) method has been described [33]. It is analogous to Prony's classical complex exponential time domain method [24].

The time shift property of the Fourier transform has been used to develop the complex exponential frequency domain (CEFD) method [34]. This is a frequency domain version of Zaghlool's single station time-domain (SSTD) method [35]. Both the real and imaginary parts of the FRFs are required; in contrast, with the FDP

method only magnitude data can be employed. The CEFD algorithm utilizes the Fourier transforms of several time-shifted versions of the free transient response. Two matrices are generated from exponentially modulated frequency responses sampled at equal frequency increments. The complex mode shapes and frequencies are obtained by solving the eigenvalue-eigenvector problem associated with a real system matrix that is formed by multiplying one of these matrices with the inverse of the second. The time shift is used in computing natural frequencies from eigenvalues.

An alternative approach for solving the nonlinear equations is based on the partial fraction expansion of FRFs by an iteration process [36]. A detailed examination of the mathematical background of several modal modeling methods is also presented.

Curve fitting methods based on the rational fraction form of the FRF have been reviewed [37]. Early rational fraction least squares (RFLS) techniques [38] are based on solutions of equations that are ill-conditioned due to the polynomial functions. A new formulation called the rational fraction orthogonal polynomial (RFOP) method has been introduced [39] and included in several modal analysis software packages. Orthogonal polynomials are used; they remove much of the ill-conditioning and do not require a simultaneous linear equation solution. Complex orthogonal polynomials, represented as sums of two so-called half-functions, are generated using the Forsythe method [40]. The polynomial coefficients of the rational fraction expressed in terms of orthogonal polynomials are computed from a set of uncoupled equations, first the denominator and then the numerator coefficients. The coefficients of the ordinary polynomials are recovered with known formulas [40]. Resonance frequencies, damping ratios, and residues are obtained by a partial fraction expansion process. Residual effects can be compensated for by specifying additional terms for the numerator polynomial only. Errors can occur when the orthogonal polynomials are undersampled over the chosen frequency range or when measurements contain excessive noise or lack sufficient frequency resolution.

Modal parameter estimates are usually affected by bias errors (leakage) and variance errors (random noise from transducers). Nonstationary effects (due to excitation and transducer mass loading) and time-dependent system characteristics cause a shift in resonance frequencies and distortion of modal vectors.

All curve fitting algorithms can give erroneous results when the degree of the curve-fitting function is overspecified. If resonance frequency estimates are generated that are not associated with global eigenvalues of the system they are sorted out by observing the phase angle between force and displacement response. Although MDOF algorithms have greatly improved the quality of modal parameters, estimation of modal damping shows considerable variance.

**Single reference multi-curve algorithms.** Multi-mode curve fitting procedures using single point excitation require that at least one column of the FRF matrix completely define the mode shapes. Analyzing one FRF curve at a time allows different estimates of natural frequency and modal damping to be derived for each mode; these are global properties. In many cases it is not possible to identify the complete modal vector due to the near-zero modal coefficients obtained as a result of the poor choice of excitation and response points. Improved frequency and damping estimates can be extracted from multiple-curve single-reference analyses. They perform an ensemble MDOF fit of FRF curves from all response stations but with the same excitation location.

Simple averaging [41] or weighted averaging [42] of parameter sets for each mode from different FRFs have been used. Alternatively, absolute values or squares of all FRFs have been averaged in a resultant function containing the resonance peaks of all modes. This function can be curve fit to obtain frequency and damping estimates. The approach has its beginnings in a technique used by de Vries [43].

Goyder [44] first suggested performing a simultaneous multi-mode fit over all FRF curves to obtain a fully self-consistent modal model. His approach has been ex-

tended to viscously damped systems [45]. A multi-curve extension of the NLSFD algorithm has been presented [46].

In one version of the global curve fitting method [47], global frequency and damping estimates were obtained by using an extended variant of the RFOP algorithm; local modal residue estimates were derived by processing FRF measurements one at a time. A similar algorithm called the complex orthogonal polynomial function (COPE) has been described [48], but the theoretical background was not given. All RFP algorithms require operator-entered values for the expected number of modes. Most global fitting methods imply simultaneous analysis of FRFs resulting from multiple single point or multi-point surveys of the tested structure.

**Multiple reference multi-curve algorithms.** Multiple reference simultaneous algorithms perform an ensemble MDOF fit of FRF curves from all response locations and several or all excitation locations. Experience with MDOF algorithms has shown that measurement of just one column of the FRF matrix poorly defines modal vectors with a near-zero modal coefficient at the excitation location. Additional columns of the FRF matrix are required to detect possible errors in the estimation of modal vectors. Richardson and Kniskern [49] showed that the variance error can be reduced by averaging two columns of an FRF matrix.

When more than one column of an FRF matrix is available (redundant data), the multiple estimates obtained for the modal parameters are generally not consistent. Inconsistencies involve frequency shifts, nonreciprocity, and nonstationarity in the data. These errors in measured FRFs are partly due to nonlinearities, to environmental effects, and to exciter and transducer attachments [5].

A systematic global approach for modal testing has been developed [42] for a hysteretically damped model. Testing conditions are adjusted to minimize the influence of nonlinearities; selected FRF curves are then analyzed, and modal parameters are derived using SDOF and MDOF algorithms. For each modal pa-

parameter a quality factor is calculated that describes the identification accuracy. The inverse of the squared quality factor is used as a weighting factor in an averaging process by which the best natural frequencies and modal dampings are determined. When redundant data are available, optimized mode shapes can be derived after modal constants are adjusted to make them consistent with the best values of frequency and damping estimates. Weighted averaging with the quality factor (WAQF) can be used with data from a single-point sine excitation.

A global rational fraction orthogonal polynomials (GRFOP) method, reformulated to estimate global mode shapes, has been described [47]. It avoids the numerical problems of the least squares error equations obtained using ordinary polynomials.

In order to eliminate the tendency of the global nonlinear least squares (GNLS) fitting method [50] to overestimate damping, a new constrained global nonlinear (CGN) method has been developed [46]. Modal identification is reduced to a minimization problem with constraints. The GNLS and CGN algorithms differ from the GRFOP and WAQF methods in that all available FRFs are simultaneously used in the quadratic error expression; in addition, the objective function is differentiated with respect to a vector containing all modal parameters. Estimations of natural frequencies and modal damping are not separated from estimations of modal vectors.

The consistency of modal vectors has been thoroughly analyzed by Allemang [5]. He calculated a least squares error estimate of the proportionally constant between columns of the residue matrix and defined a modal scale factor (MSF) as the complex ratio of the cross moment of the modal vectors to their automoment. The MSF provides a means of normalizing all estimates of the same modal model. A modal assurance criterion (MAC) is defined as a scalar constant relating the portion of the automoment of the modal vector that is linearly related to the reference modal vector [51]. The MAC provides a measure of consistency (not validity) between estimates of a modal vector.

Inclusion of data from multiple reference locations in an estimation of global properties dictates the need for consistency of measured data. This goal can be achieved by multipoint excitation and simultaneous recording of various FRFs. Multichannel parallel data-acquisition and analysis systems such as the digital data harvester [52] or the SOPEMEA facility [53] are required. Selection of excitation function [54] and configuration [55] has been discussed.

The theoretical basis of multiple input/output FRF analysis has been documented [56-58]. Early work in the experimental study of multi-input systems was concerned with the analysis of normal operating records [59, 60].

Advantages of the multiple input FRF techniques investigated by Allemang [5, 61] include better energy distribution in the system with consequent decreases in the effects of nonlinearities and excitation of local modes, reduction in test time, and increased accuracy of results due to information redundancy. Multi-input excitation requires that the input signals are non-coherent at every frequency in the sense that the input cross power spectrum matrix is not rank deficient.

It is possible to use a weighted average set of FRFs with a common exciter (or response) location to enhance specific modes of a system. The weighting function, determined in a preliminary EMA analysis, is approximately equal to the modal vector of the mode to be emphasized. The concept of enhanced FRF improves frequency and damping estimates due to a reduction in the effective number of degrees of freedom that must be considered in the fitting process.

#### DIRECT SYSTEM PARAMETER ID

Indirect modal identification methods basically perform a so-called direct system parameter identification (DSPI) [62]. A lumped mechanical system model, described by structural mass, damping, and stiffness matrices, is fitted to measurements. The estimation of modal parameters is obtained by utilizing the matrices of the physical model in the eigenvalue problem.

DSPI methods are computationally three step procedures. First the structure of the response data is simplified by a non-parametric procedure into a reduced set of enhanced frequency responses. The reduced system matrices are then estimated by a linear least squares analysis. Finally a consistent set of modal parameters of the effective dynamic system is determined by solving an eigenvalue problem using standard numerical procedures.

In the simultaneous frequency domain (SFD) technique [63], the total number of DOF is divided into a set of independent DOF equal to the number of assumed modes in the observation frequency band plus an allowance for the contribution of off-range resonant modes and a set of dependent DOF. The reduced set of equations of motion describe the motion in the independent DOF. Constraint equations are set up for the remaining DOF. The number of assumed modes is established by counting resonances in FRF curves. A pretest estimate of the mass matrix is required [62]. Modal parameters are first estimated within several frequency sub-bands, then a global refit is done in the total frequency band. A global refitting of mode shapes is performed by a least squares procedure based on fixed values of natural frequency and damping.

In the multi-matrix method [64] the number of effective DOF is established by a principal component analysis. A real covariance matrix is constructed for the response data. The singular value decomposition of this matrix is used to derive principal components of the response data; these components are called principal responses. The covariance matrix of the principal responses equals the diagonal matrix of the singular values of the original covariance matrix. When part of the singular values is larger than the remainder, the corresponding principal components represent most of the response in an observed frequency range. The remainder describes the contribution from off-range or noise modes. A reduced set of enhanced frequency responses is thus obtained.

The dimension of a response data set is reduced; then a general matrix input-output

polynomial is estimated using simultaneous multi-reference frequency responses. Residual terms rather than additional modes are used to describe the contribution of modes out of the measured frequency range. The estimated matrix coefficients are used to calculate a consistent set of modal parameters. Because the standard normal equation approach proved numerically unstable, a QR orthogonal decomposition of the coefficient matrix was applied using Householder reflections. The method is formulated to use any paired input-output frequency domain measurement; FRFs are a special case. The algorithm proved stable and robust and was able to handle structures with repeated modes and high modal damping [65]. The disadvantage of these algorithms is the increased computational requirements [66].

Indirect identification methods are used when results from system analysis and system identification differ considerably. Adjustment of the computational model by parameter improvement using measured quantities has been treated [3, 67, 68]. Parameter identification methods using input and output residuals have been compared [69, 70].

## ANALYTICAL MODAL TUNING

Modal tuning is still widely used for determining modal models in terms of normal modes, especially for structures with high modal density and high damping.

For systems with high nonproportional damping, resonance frequencies of closely spaced modes are closer to each other than corresponding undamped natural frequencies; damped natural frequencies might have reversed order. Overdamped modes do not exhibit resonance peaks or loops and cannot be detected from FRF curves. Frequency domain curve-fitting algorithms fail in this case.

Modal tuning has been used to isolate modes with closely spaced frequencies and to refine the modal parameter estimates [71]. An FFT analyzer was employed to acquire FRFs using single- or two-point excitation. Curve fitting was applied to determine preliminary modal parameters

from which analytical expressions for the FRFs were obtained as before [72]. These analytically synthesized FRFs were used as the FRF input to the standard Asher method and to the minimum coincident response method [73]. Techniques for obtaining improved modal vector estimates have been discussed [74].

Plots of eigenvalues of the real part of a square FRF matrix vs frequency permit a more accurate location of undamped natural frequencies than the determinantal plot used in the Asher method. Each curve crosses the frequency axis only once, so that modes having indefinitely close (or repeated) natural frequencies can be separated [75, 76]. All modal parameters, including modal mass and damping coefficients, are calculated from data obtained by non-appropriate excitation. They are global estimates because the entire FRF matrix is used.

If the FRF matrix is separated into real and the imaginary parts, characteristic phase lags and forced modes of excitation can be obtained by solving the generalized eigenvalue-eigenvector problem associated with these two matrices. Plots of the cosine of the characteristic phase lag vs frequency allow location of undamped natural frequencies at zero crossing. The modal mass results from the slope at these points. The complete nondiagonal matrix of modal damping coefficients can be calculated [20]. For the implementation of the method on a minicomputer, the frequency response measurements were first enhanced by a principal component analysis into a reduced set of FRFs [64]. The number of rows in the enhanced FRF matrix was close to the number of effective degrees of freedom.

There are usually fewer vibrators than transducers; the FRF matrix is thus not square. The singular values of the rectangular real part of an FRF matrix can be used to locate undamped natural frequencies in the pretest phase of a modal survey [77]. Complete tuned forcing vectors are derived from the pseudo-inverse of a submatrix of the real part of the FRF matrix. The imaginary part of the rectangular FRF matrix and the approximate forcing vectors are used to obtain

analytically the incomplete undamped modes of vibration without actually exciting them [78].

An automatic mode tuning procedure called force appropriation for modal evaluation (FAME) has been suggested [79]. An extended Asher matrix was constructed by multiplying the real part of the rectangular FRF matrix by its transpose. The frequency-dependent eigenvalues of this matrix were used to determine undamped natural frequencies and appropriated forces.

## NONLINEAR MODELS

A linear model must usually be used that best fits a nonlinear structure. Excitation level and exciter location are selected so as to better distribute energy through large structures and to diminish nonlinear behavior. The tendency is to remove nonlinearities by tightening screws, eliminating clearances, or preloading. Linear models and modified excitation must be replaced by more realistic nonlinear models and forcing patterns representative of actual operating conditions.

Techniques for modeling simple nonlinear systems with cubic stiffness [80], quadratic damping [81], and Coulomb damping [82, 83] have been reviewed [84, 85]. Methods for recognizing structural nonlinearities in harmonic testing have been developed [86-88]. Applications of the Hilbert transform to the modal analysis of nonlinear structures and use of statistical moments to identify nonlinearities have been suggested [89]. The nonlinear behavior of a structure having two closely spaced modes has been studied [90].

In a comprehensive report [91], several methods to derive a nonlinear mathematical model from resonance data were presented using the harmonic balance method. The analysis was extended to MDOF systems; it was assumed that the chosen generalized coordinates were such that each nonlinear term in the equations of motion involved only one generalized coordinate or its derivative.

The background of several nonlinear parameter estimation methods is available

[92]. A constrained version of the iterated extended Kalman filter has been formulated [93]. The method is well suited for nonlinear estimation problems in which measurement nonlinearities are high. Much work remains before nonlinear models of complex structural systems [94] will be available or the capability of known techniques to provide nonlinear analyses can be assessed. This topic will be treated in a future review article.

### CONCLUSIONS

EMA is presently considered as a process that combines test structure excitation, data measurement and acquisition, data processing and modal modeling, and model verification or modification. All parts of this process are connected and must be treated as interdependent.

The accuracy of a modal model derived from experimental data is dependent upon quality of measurements, refinement of data analysis procedures, and degree of observability of a test structure. The development of hardware and measurement procedures based on multi-input excitation and parallel multi-channel data collection will improve the consistency of data and the accuracy of modal modeling. Development of stable, robust, and easy-to-use algorithms for simultaneous data analysis; improvement in modal test productivity; and a more effective use of modal test results by the analyst are areas for further research. Noninteractive analysis techniques will not replace the need for operator expertise; pretest and post-test stages of EMA are gaining importance.

Additional applications to actual structures are required to establish the sensitivity of current curve-fitting algorithms to structural characteristics (nonlinearities, frequency-dependent properties, and close-frequency modes) and to different types of measurement errors. Model order estimation, compensation for out-of-band resonances, use of modal confidence factors for validity checks, and use of frequency-dependent modal models are topics for investigation. Extended use should be made of such common methods employed in system identification as maximum likeli-

hood, instrumental variables, bayesian estimation, and optimal filtering. These methods can complement current parameter estimation algorithms.

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## LITERATURE REVIEW: survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four reviews each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the **DIGEST** reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

## FLEXURAL RIGIDITY OF STRANDED CABLES

T.V. Gopalan\* and G.R. Nagabhushana\*\*

**Abstract.** Flexural rigidity and maximum fiber distance are important in the dynamics of the multi-stranded cables used in overhead power lines. This paper discusses a satisfactory solution based on experimental results for obtaining these parameters.

The most common stranded cables used in overhead power lines are aluminium conductor steel reinforced (ACSR) cables. High-frequency low-amplitude vibrations known as aeolian vibrations affect the mechanical performance of these cables and cause fatigue damage at points of rigid attachment of the cables. The majority of fatigue-failures occur at the ends of spans.

In ACSR cable fatigue analysis flexural rigidity and maximum length of fiber conductor are important parameters. It has been implied [1] that a multi-stranded cable behaves like a solid cable; the cable radius was assumed to be the maximum fiber distance to the span-end aluminium strands. It has been reported [2] that when the outer strand radius was used, the strands responded independently to dynamic forces on the cable. The approach followed is known to yield good results [3] when compared to measured results.

Experimental results of stranded cables [4] show that the dynamic flexural rigidity is relatively close to that of an equivalent solid cable. The maximum fiber distance for a solid conductor cable is close to the fourth root of its section moment of inertia; such experimental results therefore seem to substantiate a solid cable approach (1). A definite method for obtaining these quantities has not yet been developed.

In addition, an explanation for the higher endurance limit [5] of single layer ACSR compared to multilayer ACSR is not yet

available, nor is it known why strands in the penultimate layer of ACSR fail earlier than those in the ultimate layer. The validity of using dynamic strain in an outer strand in the vicinity of a clamp as a measure of vibration intensity should be clarified [5].

An inferential approach based on well known experimental results on ACSR cable is discussed in this paper in an attempt to examine the above aspects of overhead-cable-vibrations.

### STATIC FLEXURAL RIGIDITY

There seems to be general agreement regarding static flexural rigidity  $(EI)_s$  of multi-stranded cables. The relation is

$$(1) \quad (EI)_s = \sum_{r=1}^n E_r I_r$$

$E_r$  = Young's modulus of elasticity of  $r^{\text{th}}$  strand

$I_r$  = section moment of inertia of  $r^{\text{th}}$  strand

The strands respond independently to a static force acting on the conductor. Thus, no coupling exists between strands. The maximum fiber distance used in calculations relating to flexing of cable under static force is the radius of the concerned strand.

### DYNAMIC FLEXURAL RIGIDITY

Experimental results [4] have shown a value of 20% to 90% of the solid flexural rigidity,  $EI$ ; such a value is much more than the  $(EI)_s$  given in the equation. Coupling therefore exists between strands

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under dynamic flexing. Dynamic flexural rigidity is related to strand slippage or interstrand motion within a conductor and thus should depend on dynamic deformation of the cable [6]. Scanlan and Swart [7] showed evidence of variation of flexural rigidity with respect to span-wise position and relative freedom of the outer lay to buckle and glide. Cable curvatures caused by vibration are much larger at the supporting clamps than in the free span; the attendant sliding force readily overcomes frictional resistance, resulting in gross sliding [5]. The construction of stranded cable is also such that strands other than the outer ones are well bound.

It has been stated that most of the damping in ACSR takes place between the ultimate and penultimate layers and is due to small relative movements of strands [1]. This is adequate support for the evidence of Scanlan and Swart [7].

The relative freedom of outer strands means that they can respond independently to dynamic forces; the inner strands respond as one. The section moment of inertia and maximum fiber distance for strands of the ultimate layer as well as other layers can be calculated.

$$(2) \quad (EI)_d = n E_{al} I_{al} + (EI)_c$$

$(EI)_d$  = dynamic flexural rigidity of cable section, Figure 1

$n$  = number of strands of aluminium wires in the ultimate layer, Figure 2

$E_{al}$  = Young modulus of elasticity of aluminium

$I_{al}$  = section moment of inertia of aluminium strands in the ultimate layer

$(EI)_c$  = flexural rigidity of the composite cable except the outer layer shown in Figure 3, treating it a solid section

The maximum fiber distance for strands in the outer layer is the radius of the strand. This value can be calculated for other strands by treating the section in Figure 2 as a solid.

The ratios of dynamic flexural rigidity to solid flexural rigidity of all ACSR cables of diameter 16 mm to 31.77 mm used in India have been worked out. For ACSR Coyote (26/2.5 mm aluminium, 7/1.91 mm steel) the ratio is 0.2. For 37 stranded and 61 stranded conductors, ratios are 0.26 and 0.37 respectively. The ratio will be higher for larger diameter cables with typical strand diameters.

The values for dynamic flexural rigidity fall in the range of 20% to 90% respectively that have been reported [4]. Another estimate is 0.5 [8].

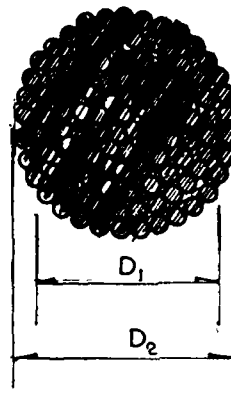


Figure 1. ACSR Cross Section

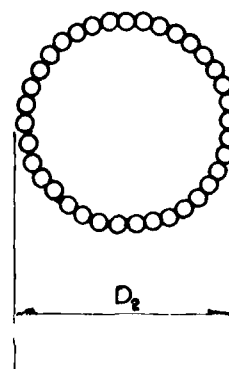


Figure 2. ACSR Cross Section Showing Wires Acting Individually

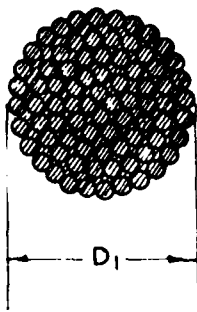


Figure 3. ACSR Cross Section  
Acting as a Monolith

### IMPLICATIONS OF THE HYPOTHESIS

The most important implication is that, in all calculations pertaining to stresses and strains in the outer layer of multi-stranded cables, the maximum fiber distance is that for the strand alone. This implication substantiates a value of  $d/2$  [2].

The analysis implies that the dynamic stresses in the strands of a penultimate layer will typically be more than those in the strands of the ultimate layer. Because strands in the penultimate layers are usually caught between strands of neighboring layers, a higher value for fretting can also be expected in the strands. The probability of failure of these strands is therefore greater than it is for those of the ultimate layer.

Because strands of the ultimate layer are in a safer state of dynamic stress, the validity of using dynamic strain in an outer layer as a measure of vibration intensity [9, 10] should be questioned. It is a corollary that a single layer ACSR cable will have higher fatigue endurance than will a multilayer ACSR cable [5].

### CONCLUSIONS

The dynamic flexural rigidity of multi-stranded conductors can be calculated using the hypothesis that the wires of the outer layer are free to slide; inner wires act as one strand. The maximum fiber distance for strands of the outer layer is the strand itself. In a multilayer ACSR cable strands

of the penultimate layer are likely to be stressed more than those of the ultimate layer. Fatigue failures are thus likely to originate in strands of the penultimate layer. Fatigue endurance of a single layer ACSR cable will exceed those of multilayer ACSR cable.

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# BOOK REVIEWS

## FRACTURE TOUGHNESS OF WELDMENTS

R.E. Zinkham, editor  
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1984, 111 pages, H00314

This book is a collection of five papers that were presented at the 1984 Pressure Vessels and Piping Conference and Exhibition June 17-21, 1984, at San Antonio, Texas. It was sponsored by the Materials and Fabrication Committee, Pressure Vessels and Piping Division of ASME.

Four of the papers are the results of a program monitored by the Metals Property Council. Large scale wide plate tests were used to evaluate the significance of small scale Charpy Vee Notch (CVN) impact tests for weldment qualifications. The CVN tests were specified by the Marine Engineering Requirements of the U.S. Coast Guard. The primary objective was to test the assumption that Charpy performance is a reliable indicator of structural performance.

The four papers are:

"Fracture Toughness of Weldments Small Scale Fracture Tests" by D.K. Scherrer, P.O. Metz, and D.A. Sarno

"Fracture Toughness of Weldments: Wide Plate Tests" by D.T. Read

"Fracture Testing of Weldments Conventional Analysis" by P.O. Metz and D.A. Sarno

"Fracture Toughness of Weldments: Elastic-Plastic Fracture Analysis" by D.T. Read

The authors of the first paper discuss the results of small scale CVN and fracture toughness tests and the rationale for selections of wide plate test conditions. The first paper by Read describes test procedures used to carry out wide plate tests at

low temperatures. Metz and Sarno used stress intensity factor and crack tip opening displacement analytical procedures to discuss wide plate results. The fourth paper employs J-Integral analytical procedures to do the same thing.

The fifth paper, "Fracture Assessment of Welded Points; Wide Plate Test with Welding Misalignments and Relation to Charpy Test," describes methods for performing surface notched wide plate tension tests with certain types of misalignments in the weld such as angular distortion and welding offset. The tests were performed on HT80 steel. Correlation of wide plate and Charpy V-notch tests was studied.

The book is well organized, the articles are well written, and the results address a general audience rather than a specific case. Testing engineers and specifications writers for most marine architectural firms would be well-advised to read this book.

K.E. Hofer  
L.J. Broutman & Assoc., Ltd.  
Technology Center  
3424 S. State St.  
Chicago, IL 60616

## COMPUTATIONAL METHODS FOR TRANSIENT ANALYSIS

T. Belytschko and T. Hughes, eds.  
Elsevier Science Publishers, New York, NY  
1983, 540 pages, \$88.00

Transient analysis of solids and fluids has recently become a subject of intense research efforts. Several publications have appeared on new formulations of the governing nonlinear equations, novel temporal integration techniques, computational strategies, and software implementations. However, until now no textbook or monograph has brought together these diverse activi-

ties. This monograph helps fill this void. The objective of the book as stated by the editors is to provide comprehensive treatment of current topics of transient analysis of solids. The topics are ones for which a certain level of maturity has been reached.

The ten chapters cover temporal integration techniques, infinite domains, geometric and material nonlinearities, and fluid-structure analysis. With regard to temporal integration techniques both classical explicit and implicit schemes and such novel schemes as operator splitting and combined explicit/implicit schemes are discussed. The authors present the material in a clear and readable form and provide the reader with a perspective of the state of the art.

Chapter 1 contains an overview of current concepts of spatial discretization for diffusion, solid mechanics, and fluid/structure interaction problems. A brief exposition is given of explicit and implicit time integration techniques and their computational implications.

The subject of temporal integration is amplified in the second chapter, which focuses on the stability of different temporal operators. Both first and second-order linear symmetric systems are discussed. Some consideration is given to nonlinear symmetric systems as well as to nonsymmetric operators typically encountered in diffusion-convection problems.

Chapter 3 reviews the partitioned analysis procedure for analyzing coupled-field dynamical problems. This is an important procedure because of the variety of engineering applications requiring tight interaction between two or more fields. Examples include fluid-structure interactions in submerged structures, pressure vessels, and piping; thermal-structure interaction in high-energy equipment; and control-structure interactions in aircraft and aerospace structures. Partitioned analysis procedures provide efficient solutions of coupled problems in stages; the process is implemented through sequential or parallel execution of single-field analysis programs. In spite of the fact that the underlying theory is in a formative stage, several partitioned analysis procedures have been developed and applied to a variety of

coupled-field problems. The chapter focuses on the formulation of the time advancing process and computer implementation. Some applications are also presented.

Application of boundary element methods to transient response analysis is the subject of Chapter 4. Discussion focuses on the advantages of combining boundary integral equation formulation (for reducing the dimensionality of the problem) with the modeling flexibility of the finite element method. Applications include transient, inviscid, irrotational incompressible flow about a submerged body; excitation of a submerged spherical shell by a transient acoustic wave; and dynamic stress concentration factor for an infinite plate with a circular hole excited by a dilatational step-wave.

Dynamic relaxation, which was originally presented as an explicit iterative method for solving steady-state (static) problems, is the subject of Chapter 5. The technique is based on the fact that a static solution is the steady-state part of the transient response for a temporal-step load. The major advantages of the technique are simple programming and low storage requirements. However, as mentioned by the authors, the technique has the disadvantage of slow convergence in finite element applications.

The phenomenon of dispersion introduced by finite difference and finite element schemes is addressed in Chapter 6. Dispersions associated with both temporal discretization and spatial semi-discretization are discussed. Ultimately, the dispersive properties of completely discretized systems are of greatest value to analysts. However, as pointed out in the chapter, several parameters exist, even for the simplest algorithms, that considerably complicate study of the combined effect.

The treatment of silent boundary methods for transient analysis is presented in Chapter 7. The authors analyze and compare several dynamic models that are designed to absorb waves radiating toward infinity in a finite computational grid. The analysis is directed primarily toward soil-structure interaction problems; the theoretical basis

for the method of extended-paraxial boundary is given. Comparison with two other well-established silent boundary techniques (for absorbing waves radiating towards infinity) is made.

Explicit Lagrangian finite difference methods are reviewed in Chapter 8. These methods have been incorporated in a series of computer programs for stress wave analysis in elasto-plastic materials. Underlying direct, explicit, second-order methods have been the foundation of well established finite-difference Lagrangian codes for more than two decades. Recent advances discussed in this chapter include development of slide lines and rezoning capabilities to avoid mesh entanglement in the case of large grid distortions. A review is given of recent work on development of constitutive equations for simulating the dynamic response of real materials including phase-change effects, accumulation of distributed damage, and other rate-dependent processes.

Implicit finite element methods for the temporal integration of linear and nonlinear problems are examined in Chapter 9. Single-step and multistep algorithms are reviewed, and computational aspects and computer implementation of nonlinear implicit integration techniques are discussed.

Recent developments in the area of arbitrary Lagrangian-Eulerian finite element methods are summarized in Chapter 10. These techniques combine some of the best features of Lagrangian and Eulerian approaches and have high potential for application to interacting media problems such as fluid-structure coupling. Emphasis has been placed on the treatment of unsteady compressible flow problems including transient fluid-structure interaction problems. An explicit time integration strategy includes an automatic rezoning capability and sliding interfaces for fluid-structure coupling. Two numerical examples of impulsively loaded pressure vessels filled with water are used to illustrate the concepts.

The monograph will be a valuable addition to the library of engineers and researchers

working on transient response of structures and solids.

A.K. Noor  
NASA Langley Research Center  
Mail Stop 246 C  
Hampton, VA 23665

## RANDOM VIBRATION IN PERSPECTIVE

W. Tustin and R. Mercado  
Tustin Institute of Technology  
Santa Barbara, CA  
1984, 200 pages, \$100.00

The authors have slanted this text toward laboratory and environmental engineering specialists (EES). As stated by the authors, "Military Standard 810D demands vastly more random vibration measurement, analysis and testing. Sinusoidal vibration barely survives. Environmental tests are to be based upon environmental measurements rather than (as before) upon classical test curves . . . The vibration and shock tests of 810D will be difficult to apply in laboratories that lack computer control."

Each of the 36 sections is short but to the point. An excellent table of abbreviations and definitions is included. The first section introduces sources of vibratory energy in automobiles and a variety of problems that relate to offices, wind force, compressor stations, aircraft or missile tests, machinery, stress screening in electronic production, transportation damage, quality control vibration measurements, vibratory feeders, and vibration isolation. The reviewer believes that flutter phenomena and cavitation should have been included.

The next section covers the specialized language of vibration, an interesting but short discussion on vibration measurements in general, helpful vibration calculations, and equations relating to fundamental terms.

Section 3 on sensors and systems for measurement of vibratory displacement includes various optical measurements, noncontacting sensors, hand-held contacting displacement

transducers, and remote testing with displacement sensors.

Sections 4 and 5 are concerned with sensors and systems that measure vibration velocity. Accelerometers are small, rugged, accurate, cover a wide frequency range, and have a flat response. Strain gage accelerometers have been widely supplanted by piezoelectric (PE), piezoresistive (PR), and servo accelerometers. The authors point out the difficulty of measuring low frequency vibration with PE accelerometers and the accurate charge signal conditioning now available. The concluding part elaborates disadvantages of accelerometers.

Section 6 continues the discussion of sensors and systems for force measurement. Driving point sensors (impedance heads) and impact hammers are described. Impedance, mobility, inertance, dynamic mass, compliance, and dynamic stiffness are defined.

Section 7 describes the analysis of complex vibration, including analyzers and spectra. A short description of random vibration and power spectral density are given, but auto- and cross-correlation and cross-spectrum are not discussed, even though they are important in both testing and analysis.

Section 8 considers machinery health monitoring and spectrum analysis. Interpretations of spectra and sources of machinery vibration and methods for identifying them are given. The importance of baseline spectral data is emphasized.

Section 9 considers calibration of vibration measuring systems; techniques include optical, interferometry, and reciprocity. Forms of calibration are described. The fact that a test engineer must calibrate an entire system rather than individual parts is stressed.

Section 10 covers mechanical shakers. Section 11 describes electrohydraulic shakers. Section 12 focuses on electromagnetic shakers, which are the most widely used and accurate. Section 13 is concerned with power amplifiers for electromagnetic shakers.

Section 14 has to do with analog controls for sinusoidal testing. Section 15 contains details of the digital control of sinusoidal testing. Section 17 summarizes sinusoidal testing standards. Section 17 describes procedures for carrying out sinusoidal vibration tests still used in fatigue, resonance, and qualification testing.

Section 18 describes orthogonal motion. Section 19 outlines the characteristics of fixtures used in tests. A table shows design criteria for various sizes of fixtures, but the small print is difficult to read.

The next two sections describe auxiliary devices for testing large loads; they include slip tables, hydrostatic bearing tables, and head expanders. Section 22 is concerned with measurement and analysis of random signals. The authors introduce spectral density, probability density, variance, and standard deviation. A discussion of narrow-band random response concludes the section.

Section 23 describes a procedure for devising random vibration test specifications. A random spectrum plot is explained; methods for obtaining total rms acceleration under a given test curve are given. Section 24 has to do with the signal source for random vibration testing. Section 25 is concerned with analog equalization for random vibration testing. Computer control of random vibration testing is covered in Section 26. The microcomputer is the heart of the system.

Section 27 has to do with protecting shaker and specimen from the large mechanical forces generated in a shaker armature. The next two sections briefly describe earth motion measurements and seismic testing. Displacement, velocity, acceleration, and force sensors used in torsional vibration are considered next. Shaker and slip tables for torsional vibration are described.

Section 30 is a survey of stress screening, an electronic test concept that increases reliability.

Section 31 on acoustic environment testing has to do with ascertaining possible fatigue failures close to jet engine exhaust and

spacecraft during ascent and descent. Acoustic inputs are also used in stress screening.

The topics of Section 32 include shock measurements, calibration, analysis, and design. The authors propose ways in which shock transients can be recorded. Section 33 is about shock testing.

This book will be useful to the technician and test engineer. Topics that should have been expanded are: modal analysis; data processing including the FFT; use of Campbell's and waterfall diagrams in testing rotating machinery; flutter of wings, turbine, and compressor blades and their relation to vibration testing; simple derivations of vibratory equations; random vibration and applications of random fatigue testing of structures and elements; Gaussian and random curves; strain gages; and telemetry systems -- i.e., fundamentals and method of operation in aerospace and turbine applications. The explanations that are given are stated in simple language and are good.

H. Saunders  
1 Arcadian Drive  
Scotia, NY 12302

#### MEASUREMENT SYSTEMS -- APPLICATION AND DESIGN

E.O. Doebelin  
McGraw-Hill Book Co., New York, NY  
3rd Edition, 1983, 876 pages, \$39.50

This book contains information for the mechanical engineer on electronics, data recording, data processing, equipment, and instrumentation. It covers measurements of pressure, sound, flow, temperature, and vibration. In this new edition all references to vacuum-tube electronics have been replaced by references to solid-state equivalents; emphasis is on digital computer applications. The many references should aid the reader in his quest for knowledge of instrumentation.

The book contains 13 chapters in three parts. Part I is general. Chapter 1 dis-

cusses applications of measurement instrumentation including introductory control and monitoring of processes and operations. Chapter 2 describes generalized configurations and functional description of measuring instruments: active and passive transducers, analog and digital modes of operation, and methods of correction for inputs. Chapter 3 reports on generalized performance characteristics of instrumentation.

Part 2 contains details of measuring devices. Chapter 4 on motion measurements describes strain gages, differential transformers, potentiometers, eddy current noncontacting transducers, and electro-optical and photographic devices. Videotape systems for high-speed industrial measurements and optical holography (laser based optical techniques) applied to vibration measurements are included as are relative velocity, translational and rotational methods, and instrumentation. The mechanical flyball angular-velocity sensor, pulse counting methods, AC and DC tachometer generators, and velocity transducers (moving coil and moving magnetic pickups) are covered. The next section describes relative acceleration measurements, seismic velocity and displacement pickups, and various forms of seismic acceleration pickups. The concluding sections have to do with calibration of vibration pickups, jerk pickups, and pendulous and gyroscopic angular displacement and velocity sensors.

Chapter 5 is expanded over the previous edition. It emphasizes force and shaft power and torque measurements. Included are basic methods of force measurement and characterization of elastic force transducers such as bonded strain gages and piezoelectric types. The chapter concludes with torque measurements on rotating shafts, dynamometer measurements, gyroscopic force and torque measurements and vibrating force wire transducers. The next chapter on pressure and sound measurement describes basic methods of pressure measurement, elastic and force balance transducers, dynamic testing of pressure measuring systems, high and low measurements, and various measuring instruments. The concluding section of this chapter covers sound measurements using microphones, sound level meters, capacitor mi-

crophones, pressure-signal multi-plexing systems, and acoustic emission. The reviewer feels that the acoustic section is too brief and should be expanded. Reference should be made to the new acoustic-intensity method; acoustic emission should be expanded.

The topics covered in Chapter 7 on flow measurements include local flow-velocity and direction, gross volume flow rate, gross mass flow rate, the laser-doppler velocimeter, the vortex shedding flow-meter, and cross-correlation. The reviewer believes that cross-correlation should be expanded to include partial and multiple correlation. They have assumed important roles in determining turbulent flow characteristics and unwanted noise in flow systems.

Topics in Chapter 8 on temperature and flow measurements include thermal expansion instruments -- thermometers, thermocouples, and electron resistant and semi-conductor sensors -- and the use of semi-conductor sensors such as diodes and transistors. Other topics are instruments used in radiation measurements, temperature measuring problems in flowing fluids, and dynamic responses of temperature sensors and heat-flux sensors. Chapter 9 considers miscellaneous measurements: time, frequency, and phase angle measurements and liquid level and humidity measurements.

Part 3 is concerned with recording and manipulating data. Chapter 10 describes computation, manipulation, and compensation devices. Topics include bridge currents, amplifiers and converters, filters, a brief discussion of filtering by statistical averaging, mechanical filters for accelerometers, and integration and differentiation of signals with respect to time. Digital computer programs are given. Additional topics include dynamic compensation, function generation and linearization, and system and signal analyzers. Analog-to-digital and digital-to-analog converters conclude the chapter.

Chapter 11 presents various aspects of data transmission: cable transmission of analog

voltage and current signals, cable transmission of digital data, radio telemetry, pneumatic transmission, slip rings, and rotary transformers. A section on fiber optic data transmission points out the desirable feature of transmitting analog and digital information. The reviewer would prefer a more detailed section on fiber optics.

The next chapter relates to voltage indicator and recording devices. The section on primary standards and calibration provides graphical information for voltage resistance, capacitance, and inductance. Analog and digital voltmeters and potentiometers, optical galvanometer oscillographs, optical light gate array recorders, fiberoptic recording oscilloscopes, digital waveform recorders, digital printers/plotters, and speech-input-output devices are also considered.

The last chapter focuses on data acquisition and processing systems. A versatile modular system that employs digital control logic and digital readout but relies on analog methods for data recording is described. Compact data loggers, instrumentation connection systems that coordinate data gathered from sensing devices, and microprocessor systems that lessen the burden of a host computer are considered. A simple but thorough computer program shows the utility of this type of system.

The reviewer would have liked greater detail on some subjects and a section on experimental modal analysis. A detailed section on digital processing would be beneficial. The author should be congratulated for making the material readable and comprehensible. The reviewer would suggest that a future edition be divided into two volumes and incorporate the above suggestions. I recommend this book to designers and analysts -- including test engineers who must understand test systems and their applications -- who desire a working knowledge of measurement systems.

H. Saunders  
1 Arcadian Drive  
Scotia, NY 12302

# SHORT COURSES

## JULY

### **MACHINERY INSTRUMENTATION AND DIAGNOSTICS**

Dates: July 15-19, 1985  
Place: Carson City, Nevada  
Dates: September 10-13, 1985  
Place: New Orleans, Louisiana  
Dates: September 24-27, 1985  
Place: Anaheim, California  
Dates: October 8-11, 1985  
Place: Philadelphia, Pennsylvania  
Dates: October 21-25, 1985  
Place: Carson City, Nevada  
Dates: November 5-8, 1985  
Place: Boston, Massachusetts  
Dates: December 3-6, 1985  
Place: Houston, Texas

Objective: This course is designed for industry personnel who are involved in machinery analysis programs. Seminar topics include a review of transducers and monitoring systems, machinery malfunction diagnosis, data acquisition and reduction instruments, and the application of relative and seismic transducers to various types of rotating machinery.

Contact: Customer Information Center, Bently Nevada Corporation, P.O. Box 157, Minden, NV 89423 - (702) 782-3611, Ext. 9242.

### **MECHANICS OF HEAVY-DUTY TRUCKS AND TRUCK COMBINATIONS**

Dates: July 15-19, 1985  
Place: Ann Arbor, Michigan  
Objective: This course describes the physics of heavy-truck components in terms of how these components determine the braking, steering, and riding performance of the total vehicle. Covers analytical methods, parameter measurement procedures, computational and test procedures,

useful for performance analysis prediction and design.

Contact: College of Engineering, The University of Michigan, Chrysler Center - North Campus, Ann Arbor, MI 48109-2092 - (313) 764-8490.

### **FINITE ELEMENTS IN MECHANICAL AND STRUCTURAL DESIGN A: LINEAR STATIC ANALYSIS**

Dates: July 15-19, 1985  
Place: Ann Arbor, Michigan  
Objective: Presents energy formulation and modeling concepts. For engineers requiring stress, strain and displacement information. Attendees use personal computers to develop models of several problems and use MSC/NASTRAN in laboratory sessions. No previous finite element experience is required.

Contact: College of Engineering, The University of Michigan, Chrysler Center - North Campus, Ann Arbor, MI 48109-2092 - (313) 764-8490.

### **FUNDAMENTALS OF COMPUTER AIDED ENGINEERING, DESIGN AND MANUFACTURING**

Dates: July 29 - August 2, 1985  
Place: Provo, Utah  
Objective: This short course gives an overview of state-of-the-art computer aided techniques in engineering, design, and manufacturing with the intent of providing those engaged in CAEDM activities the opportunity to learn of the range of equipment and software that is currently available, see these tools operate, and be assisted in incorporating such tools to individual needs. Emphasis on an integrated computer assisted approach will be stressed.

Contact: Steven E. Benzley, 368L CB, Brigham Young University, Provo, Utah 84602 - (801) 378-6322.

## AUGUST

### BASICS OF VIBRATION DAMPING TECHNOLOGY

Dates: August, 1985

Place: Dayton, Ohio

Objective: A four day intensive seminar/workshop on basic damping technology, including viscoelastic material behavior, nomograms for representing effects of frequency and temperature on real material behavior, single degree and multiple degree of freedom systems, free layer, constrained layer and discrete damping techniques, and measurement basics will be given. Highlights include a new textbook on vibration damping, extensive use of participant exercises, worksheets and calculator applications to reinforce the learning process, and detailed evaluation of case histories. Attendance will be strictly limited to ensure an intensive and interactive work experience.

Contact: Dr. D. Jones, Damping Technology Information Services, Box 33514, Wright-Patterson AFB, OH 45433-0514.

### MECHANICAL ENGINEERING

Dates: August 12-16, 1985

Place: Carson City, Nevada

Objective: This course is designed for mechanical, maintenance, and machinery engineers who are involved in the design, acceptance testing, and operation of rotating machinery. The seminar emphasizes the mechanisms behind various machinery malfunctions. Other topics include data for identifying problems and suggested methods of correction.

Contact: Customer Information Center, Bently Nevada Corporation, P.O. Box 157, Minden, NV 89423 - (702) 782-3611, Ext. 9243.

### MODAL TESTING OF MACHINES AND STRUCTURES

Dates: August 13-16, 1985

Place: Nashville, Tennessee

Objective: Vibration testing and analy-

sis associated with machines and structures will be discussed in detail. Practical examples will be given to illustrate important concepts. Theory and test philosophy of modal techniques, methods for mobility measurements, methods for analyzing mobility data, mathematical modeling from mobility data, and applications of modal test results will be presented.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 101 West 55th Street, Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

### MACHINERY VIBRATION ANALYSIS

Dates: August 13-16, 1985

Place: Nashville, Tennessee

Dates: Oct. 29 - Nov. 1, 1985

Place: Oak Brook, Illinois

Objective: This course emphasizes the role of vibrations in mechanical equipment instrumentation for vibration measurement, techniques for vibration analysis and control, and vibration correction and criteria. Examples and case histories from actual vibration problems in the petroleum, process, chemical, power, paper, and pharmaceutical industries are used to illustrate techniques. Participants have the opportunity to become familiar with these techniques during the workshops. Lecture topics include: spectrum, time domain, modal, and orbital analysis; determination of natural frequency, resonance, and critical speed; vibration analysis of specific mechanical components, equipment, and equipment trains; identification of machine forces and frequencies; basic rotor dynamics including fluid-film bearing characteristics, instabilities, and response to mass unbalance; vibration correction including balancing; vibration control including isolation and damping of installed equipment; selection and use of instrumentation; equipment evaluation techniques; shop testing; and plant predictive and preventive maintenance. This course will be of interest to plant engineers and technicians who must identify and correct faults in machinery.

Contact: Dr. Ronald L. Eshleman, Director, The Vibration Institute, 101 West 55th Street, Suite 206, Clarendon Hills, IL 60514 - (312) 654-2254.

#### **BALANCING OF ROTATING MACHINERY**

Dates: August 13-16, 1985

Place: Nashville, Tennessee

Objective: This course will emphasize the practical aspects of balancing in the shop and field including training on basics, the latest techniques, and case histories. The instrumentation, techniques, and equipment pertinent to balancing will be elaborated with case histories. Demonstrations of techniques with appropriate instrumentation and equipment are scheduled. Specific topics include: basic balancing techniques (one- and two-plane); field balancing; balancing machines and facilities; use of programmable calculators; turbine-generator balancing; balancing sensitivity; factors to be considered in high speed balancing; effect of residual shaft bow on unbalance; tests on balancing machines; flexible rotor balancing --training and techniques; a unified approach to flexible rotor balancing; and coupling balancing.

Contact: Dr. Ronald L. Eshleman,  
Director, The Vibration Institute, 101 West  
55th Street, Suite 206, Clarendon Hills, IL  
60514 - (312) 654-2254.

#### **VIBRATION MEASUREMENT AND MODAL ANALYSIS**

Dates: August 15-17, 1985

Place: Amherst, New York

Objective: This course covering dynamic and measurement systems, dynamic signals, applied signal analysis, vibration fundamentals and applied modal analysis will provide engineers with a background in both fundamental and applied aspects of vibration and modal testing. The course will be taught in a lecture/demonstration format making considerable in-class use of state of the art signal analysis and modal analysis instrumentation. Hands on lab experience will be available through informal evening sessions.

Contact: Mike Murphy, Kistler Instrument Corporation, 75 John Glenn Drive, Amherst, NY 14120 - (716) 691-5100.

#### **VIBRATION AND SHOCK SURVIVABILITY, TESTING, MEASUREMENT, ANALYSIS, AND CALIBRATION**

Dates: August 26-30, 1985

Place: Santa Barbara, California

Dates: December 2-6, 1985

Place: Santa Barbara, California

Dates: February 3-7, 1986

Place: Santa Barbara, California

Dates: March 10-14, 1986

Place: Washington, DC

Dates: May 12-16, 1986

Place: Detroit, Michigan

Objective: Topics to be covered are resonance and fragility phenomena, and environmental vibration and shock measurement and analysis; also vibration and shock environmental testing to prove survivability. This course will concentrate upon equipments and techniques, rather than upon mathematics and theory.

Contact: Wayne Tustin, 22 East Los Olivos Street, Santa Barbara, CA 93105 -(805) 682-7171.

#### **OCTOBER**

#### **VIBRATIONS OF RECIPROCATING MACHINERY**

Dates: Oct. 29 - Nov. 1, 1985

Place: Oak Brook, Illinois

Objective: This course on vibrations of reciprocating machinery includes piping and foundations. Equipment that will be addressed includes reciprocating compressors and pumps as well as engines of all types. Engineering problems will be discussed from the point of view of computation and measurement. Basic pulsation theory --including pulsations in reciprocating compressors and piping systems -- will be described. Acoustic resonance phenomena and digital acoustic simulation in piping will be reviewed. Calculations of piping vibration and stress will be illustrated with examples and case histories. Torsional vibrations of systems containing engines and pumps, compressors, and generators, including gearboxes and fluid drives, will be covered. Factors that should be considered during the design and analysis of foundations for engines and compressors will be discussed. Practical aspects of the vibrations of reci-

procating machinery will be emphasized. Case histories and examples will be presented to illustrate techniques.

Contact: Dr. Ronald L. Eshleman,  
Director, The Vibration Institute, 101 West  
55th Street, Suite 206, Clarendon Hills, IL  
60514 - (312) 654-2254.

## NOVEMBER

### **MACHINERY INSTRUMENTATION**

Dates: November 12-14, 1985  
Place: Calgary, Alberta, Canada

Objective: This seminar provides an in-depth examination of vibration measurement and machinery information systems as well as an introduction to diagnostic instrumentation. The three-day seminar is designed for mechanical, instrumentation, and operations personnel who require a general knowledge of machinery information systems. The seminar is a recommended prerequisite for the Machinery Instrumentation and Diagnostics Seminar and the Mechanical Engineering Seminar.

Contact: Customer Information Center,  
Bently Nevada Corporation, P.O. Box  
157, Minden, NV 89423 - (702) 782-3611,  
Ext. 9243.

# ABSTRACTS FROM THE CURRENT LITERATURE

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## AVAILABILITY OF PUBLICATIONS ABSTRACTED

None of the publications are available at SVIC or at the Vibration Institute, except those generated by either organization.

**Periodical articles, society papers, and papers presented at conferences** may be obtained at the Engineering Societies Library, 345 East 47th Street, New York, NY 10017; or Library of Congress, Washington, D.C., when not available in local or company libraries.

**Government reports** may be purchased from National Technical Information Service, Springfield, VA 22161. They are identified at the end of bibliographic citation by an NTIS order number with prefixes such as AD, N, NTIS, PB, DE, NUREG, DOE, and ERATL.

**Ph.D. dissertations** are identified by a DA order number and are available from University Microfilms International, Dissertation Copies, P.O. Box 1764, Ann Arbor, MI 48108.

**U.S. patents and patent applications** may be ordered by patent or patent application number from Commissioner of Patents, Washington, D.C. 20231.

**Chinese publications**, identified by a CSTA order number, are available in Chinese or English translation from International Information Service, Ltd., P.O. Box 24683, ABD Post Office, Hong Kong.

**Institution of Mechanical Engineers publications** are available in U.S.: SAE Customer Service, Dept. 676, 400 Commonwealth Drive, Warrendale, PA 15096, by quoting the SAE-MEP number.

When ordering, the pertinent order number should always be included, not the DIGEST abstract number.

A List of Periodicals Scanned is published in issues, 1, 6, and 12.

# MECHANICAL SYSTEMS

## ROTATING MACHINES

85-1056

### Vibrations in Rotating Machinery

D.J. Haines

British Aerospace Dynamics, Hatfield, UK  
Chart. Mech. Engrg., 31 (11), pp 54-55  
(Nov 1984), 2 figs

**KEY WORDS:** Rotating machinery, Vibration control, Nonlinear theories, Harmonic response, Subharmonic oscillations

In the period 1980 to 1984 in excess of 500 papers on rotating machinery dynamics were published. Analysis and control of nonlinear effects that generate harmonic and sub-harmonic motions in rotating systems were emphasized. This modern approach in gyrodynamic technology is aimed at improved stability, instrument accuracy, and reduced cost of system performance.

85-1057

### The Measurement of Shaft Torque Using an Optical Encoder

D.W. Auckland, S. Sundram, R. Shuttleworth, E.I. Posner

Electrical Engrg. Labs., The University, Manchester M13 9PL, UK

J. Phys. E: Sci. Instrum., 17 (12), pp 1193-1198 (Dec 1984), 4 figs, 6 refs

**KEY WORDS:** Shafts, Torque, Proximity probes

A contactless method of measuring torque in a rotating shaft is described. A high resolution optical encoder is used to sense torsion. Output is processed digitally. The method is sensitive and has been applied to the measurement of transient torques in the drive shaft of a small motor-alternator set used to model practical turbo generators.

85-1058

### Control of Rotordynamic Instability in a Typical Gas Turbine's Power Rotor System

N.M. Veikos, R.H. Page, E.J. Tornillo

AVCO Lycoming Div., Stratford, CT 06497  
Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 53-79, 18 figs, 7 refs

**KEY WORDS:** Stability, Rotors, Turbomachinery, Internal friction

The stability of rotor systems operating above the first critical speed is affected by internal friction commonly caused by sliding press fits or sliding splines. Under conditions of high speed and low bearing damping, such systems occasionally whirl. This subsynchronous precession is a self-excited phenomenon that creates stress reversals. The reduction of spline friction or the inclusion of squeeze-film damping have controlled the instability.

85-1059

### Preliminary Investigation of Labyrinth Packing Pressure Drops at Onset of Swirl-Induced Rotor Instability

E.H. Miller, J.H. Vohr

General Electric Co., Schenectady, NY 12345

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 281-294, 12 figs, 9 refs

**KEY WORDS:** Rotors, Fluid-induced excitation, Subsynchronous vibration, Seals

Backward and forward subsynchronous instability was observed in a flexible model test rotor under the influence of swirl flow in a straight-through labyrinth packing. The packing pressure drop at the onset of instability was measured for a range of operating speeds, clearances and inlet swirl conditions. Diverging clearances were also destabilizing and had a forward orbit with forward swirl and a backward orbit with reverse swirl.

**85-1060**

**Parametric Vibration of a Prismatic Shaft with Non-Linear Heredity**

Hoang Van Dao

The Polytechnical Univ. of Hanoi, Dept. of Mathematics and Physics, Socialist Republic Vietnam

*Strojnický Časopis*, **35** (5), pp 571-582 (1984), 4 figs, 10 refs

**KEY WORDS:** Shafts, Parametric vibration, Viscous damping

Four resonance cases exist that have not been treated in the literature. It is shown that nonlinear heredity has a strong influence upon the response of steady state vibrations, especially in systems with a softening characteristic.

**85-1061**

**Rotational Ratio Response Analysis of Flexible Rotor Vibrating System**

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Hitachi, Ltd., 502 Kandatsu-machi Tsuchiura-shi, Ibaraki, Japan 300

*Bull. JSME*, **27** (234), pp 2847-2856 (Dec 1984), 20 figs, 1 table, 9 refs

**KEY WORDS:** Flexible rotors, Quasi-modal analysis, Harmonic excitation

A new method is developed for analyzing rotor vibration due to excitation at frequencies that are multiples of rotational speed. The quasi-modal transformation is characterized by mode synthesis of two mode shapes. One is obtained by undamped critical speed analysis of rotor shafting restricted at its bearing points. The other is a deflection mode shape caused by forced displacement on bearing points. The method is effective in the analysis of harmonic vibration response of a rotor with multi-level shafting.

**85-1062**

**Lasers Align Shafts - Precisely**

D. Pattinson

INA Bearing Co., Ltd.

*Chart. Mech. Engrg.*, **31** (11), pp 58-59 (Nov 1984), 2 figs

**KEY WORDS:** Shafts, Alignment, Lasers

This article describes a recently introduced purpose-designed laser system for shaft alignment.

**85-1063**

**Development of Low Noise Vacuum Vane Pumps**

H.P. Berges, D. Vorberg

Leybold-Heraeus GmbH, Cologne, Fed. Rep. Germany

Rept. No. BMFT-FB-HA-84-9, 100 pp (Mar 1984), N84-28094 (In German)

**KEY WORDS:** Pumps, Noise reduction

Noise parameters were examined during the development of a vacuum pump with flow rate 630 cum/hr. A modified serial pump was built. Noise reduction was obtained by substituting air cooling with water cooling, reduced engine speed, and resonance absorption by a modified structure. Results show a sound pressure level of 66 dB at 1 m distance.

**85-1064**

**Influence of Stationary Components on Unsteady Flow in Industrial Centrifugal Compressors**

L. Bonciani, L. Terrinoni

Nuovo Pignone, Florence, Italy

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 429-479, 49 figs, 3 tables, 25 refs

**KEY WORDS:** Centrifugal compressors, Fluid-induced excitation

An experimental investigation was performed to determine the characteristics of rotating nonuniform flow in a low speed stage, utilized in high-pressure applications, relative to change of stationary component

geometry. Four configurations, differing only in return channel and crossover geometry, were tested on an atmospheric pressure open loop test rig. Return channel geometry affected flow. Experimental results were interpreted in the light of Emmons - Stenning's rotating stall theory.

**85-1065**

**Internal Hysteresis Experienced on a High Pressure Syn Gas Compressor**

F.Y. Zeidan

Qatar Fertiliser Co., Umm Said, Qatar  
Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 97-108, 9 figs, 9 refs

**KEY WORDS:** Centrifugal compressors, Hysteretic damping, Self-excited vibrations

A vibration instability was experienced in high pressure syn gas centrifugal compressors. Tape recordings of run up and coast down data presented a clue to the cause of the instability - internal hysteresis. The problem was complicated by seal lock-up at the suction end of the compressor. A coupling lock-up problem and a coupling fit problem that caused fretting of the shaft should not be counted out as contributors to the self-excited vibrations.

**85-1066**

**Experimental On-Stream Elimination of Resonant Whirl in a Large Centrifugal Compressor**

G.I. Bhat, R.G. Eierman

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Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 81-95, 9 figs, 1 table, 4 refs

**KEY WORDS:** Centrifugal compressors, Whirling

Diagnosis of a severe resonant whirl condition was made easy by a large-scale com-

puterized machinery condition monitoring system ("MACMOS"). This system was able to verify that the predominant subsynchronous whirl frequency locked in on the first resonant frequency of the compressor rotor and did not vary with compressor speed. Stability calculations showed the rotor system had excessive bearing stiffness as well as inadequate effective damping.

**85-1067**

**Subsynchronous Vibrations in a High Pressure Centrifugal Compressor: A Case History**

B.F. Evans, A.J. Smalley

Southwest Res. Inst., San Antonio, TX 78284

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 17-36, 22 figs, 1 table, 8 refs

**KEY WORDS:** Centrifugal compressors, Subsynchronous vibration

This paper documents two distinct aerodynamically excited vibrations in a high pressure low-flow centrifugal compressor. Measured data show dependence on speed, discharge pressure, and changes in bearing design. Analytical results provide strong evidence for the exciting mechanisms of diffuser stall and aerodynamic cross-coupling. Additional results show that rotor characteristics would be expected to change as a result of proposed modifications. Satisfactory operation after modifications is described.

**85-1068**

**Full Load Testing in the Platform Module Prior to Tow-Out: A Case History of Subsynchronous Instability**

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Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College

Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 1-16, 9 figs, 13 refs

**KEY WORDS:** Subsynchronous vibration, Centrifugal compressors

The objectives of this paper are to provide a case history for students of subsynchronous instability and to discuss empirical criteria for subsynchronous instability. The benefits of pre-commissioning tests at rated speed and rated gas conditions. The case history is a practical example for the petroleum industry. The case is also of theoretical interest because of two aerodynamic features of the initial test: vaned diffusers on all stages and blocked flow passage on one impeller.

**85-1069**

**Experiences with Nonsynchronous Forced Vibration in Centrifugal Compressors**

D.R. Smith, J.C. Wachel  
Engineering Dynamics Inc., San Antonio, TX 78232

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 37-52, 9 figs, 1 table, 5 refs

**KEY WORDS:** Centrifugal compressors, Nonsynchronous vibration

Subsynchronous vibration of a compressor rotor is generally considered a shaft instability problem associated with rotor stability on the bearing oil film. When high subsynchronous vibrations are forced vibrations caused by flow instabilities, changing the bearings or seals has little effect. It is therefore important to understand differences between forced vibrations and self-excited vibrations. A list of characteristics of the two types of subsynchronous vibration is given.

**85-1070**

**Lateral Fluid Forces Acting on a Whirling Centrifugal Impeller in Vaneless and Vaned Diffuser**

H. Ohashi, H. Shoji

Univ. of Tokyo, Tokyo 113, Japan  
Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 109-122, 14 figs, 3 tables, 3 refs

**KEY WORDS:** Impellers, Fluid-induced excitation, Whirling

A two-dimensional impeller in a parallel-walled vaneless and vaned diffuser whirled on a circular orbit with various positive and negative angular velocities. Results showed that fluid forces exert a damping effect on the rotor in most operating conditions, but become excitatory when the impeller operates at very low partial discharge while rotating far faster than the whirl speed. The fluid forces were also expressed in terms of mass, damping, and stiffness matrices.

**85-1071**

**Two-Dimensional Unsteady Analysis of Fluid Forces on a Whirling Centrifugal Impeller in a Volute**

Y. Tsujimoto, A.J. Acosta, C.E. Brennen  
Osaka Univ., 560 Toyonaka, Osaka, Japan  
Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 161-172, 1 fig, 3 refs

**KEY WORDS:** Impellers, Fluid-induced excitation, Whirling

The work accounts for the effects of a volute and the shed vorticity. An impeller with an infinite number of vanes rotates with a constant velocity; its center whirls with a constant eccentric radius and constant whirling velocity.

**85-1072**

**Hydraulic Forces on a Centrifugal Impeller Undergoing Synchronous Whirl**

P.E. Allaire, C.J. Sato, L.A. Branagan  
Univ. of Virginia, Charlottesville, VA 22901

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 123-135, 3 figs, 3 tables, 16 refs

**KEY WORDS:** Impellers, Fluid-induced excitation, Whirling, Finite element technique

A method for calculating forces in a two-dimensional orbiting impeller in an unbounded fluid with nonuniform entering flow is given. A finite element model of the full impeller is employed to solve the inviscid flow equations. Five forces acting on the impeller are included. Both principal and cross-coupled stiffness coefficients are calculated for the impeller. Agreement with experimental results is fair.

**85-1073**

**Hydrodynamic Impeller Stiffness, Damping, and Inertia in the Rotordynamics of Centrifugal Flow Pumps**

B. Jery, A.J. Acosta, C.E. Brennen, T.K. Caughey  
California Inst. of Technology, Pasadena, CA 91125

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 137-160, 15 figs, 1 table, 14 refs

**KEY WORDS:** Impellers, Centrifugal pumps, Stiffness coefficients, Damping coefficients, Whirling

Experiments were conducted for various flow coefficients and impeller rotating speeds or angular frequencies. The angular frequency of the whirl motion was varied from zero to nearly synchronous and to nearly anti-synchronous. The lateral forces were decomposed into time averaged lateral forces and hydrodynamic force matrices. The force matrices consist of equal diagonal terms and skew-symmetric off-diagonal terms, the impeller thus experiences forces acting normal and tangential to the locus of whirl.

## POWER TRANSMISSION SYSTEMS

**85-1074**

**Electro-Hydraulic Digital Control of Cone-Roller Toroidal Traction Drive Automatic Power Transmission**

H. Tanaka, T. Ishihara  
Yokohama National Univ., Yokohama, 240 Japan

J. Dynam. Syst., Meas. Control, Trans. ASME, 106 (4), pp 305-310 (Dec 1984), 19 figs, 6 refs

**KEY WORDS:** Power transmission systems, Automatic transmission

The paper presents design features of the electrohydraulic interface between micro-computer and cone-roller toroidal traction drive CVT, dynamic characteristics of cone roller motion. Test results of the practical computer control of CVT are shown.

## METAL WORKING AND FORMING

**85-1075**

**Development of Non-Linear Dynamic Data System (NLDDS) for On-Line Machining Vibratory System Characterization**

Hsin-Yi Lai  
Ph.D. Thesis, The Univ. of Wisconsin-Madison, 375 pp (1984), DA8421941

**KEY WORDS:** Computer programs, Monitoring techniques, Machining

A three-stage modeling procedure is introduced for on-line monitoring of various cutting processes in turning. One simulated process and two real cases were used to check the effectiveness of this new methodology. The method provides some degree of unification and flexibility, permitting more detailed analysis of actual machining processes.

## BRIDGES

85-1076

### An Adaptable Simulator for Robot Arm Dynamics

M.S. Pfeifer, C.P. Neuman  
IBM Corp., Gaithersburg, MD  
Computers Mech. Engrg., 2 (3), pp 57-64  
(Nov 1984), 3 figs, 2 tables, 29 refs

**KEY WORDS:** Robots, Simulation, Computer programs

Vast versatile robot arm dynamic simulation tool is a program designed to allow the user to gain a physical understanding of robot and actuator dynamics and to implement and evaluate robot control algorithms.

85-1077

### The Influence of Wet-End Vibrations on Machine-Direction Basis-Weight Variations

J. Perrault  
CIP Res. Ltd., 179 Main St. West, Hawkesbury, Ontario, Canada  
Tappi J., 62 (7), pp 62-65 (July 1984), 12 figs, 10 refs

**KEY WORDS:** Industrial facilities, Paper products

Pressure pulsations can result in machine-direction (MD) basis-weight variations if improperly attenuated. Air-padded headboxes or those with external attenuation adequately dampen pulsations above 1-2 Hz; the latter do not generally affect MD basis-weight uniformity. Wet-end vibrations can translate into pronounced MD basis-weight variations, particularly in the range of 10-40 Hz. Examples include basis-weight variation and vibration frequency spectra.

85-1078

### Impact and Fatigue in Open Deck Steel Truss and Ballasted Prestressed Concrete Railway Bridges

Ton-Lo Wang  
Ph.D. Thesis, Illinois Inst. of Technology, 141 pp (1984), DA8425314

**KEY WORDS:** Railroad bridges, Moving loads, Vehicle-structure interaction, Fatigue life

A model was developed in which each truck frame/axle set was treated as a single rigid mass only in the lateral and yaw directions. Equations of motion for bridge and vehicle interaction were developed. Rail irregularities were generated according to power spectrum density functions. A partial bridge model was used to study the dynamic behavior of critical members. The concept of semirigid connection was introduced. Fatigue data were collected and S-N regression lines were obtained for riveted and plain plates. Impact factors for prestressed concrete bridges were considered.

85-1079

### Stability and Nonlinear Response of Deck-Type Arch Bridges

K.Y. Medallah  
Ph.D. Thesis, Michigan State Univ., 234 pp (1984), DA8424451

**KEY WORDS:** Bridges, Amplification factor method

An amplification factor method used in this study has a form similar to that used in the design of beam-columns. Eigenvalues (and corresponding eigenvectors) or buckling loads of structures were studied. Two three-dimensional numerical model bridges were constructed. Predictions of nonlinear responses using the amplification

factor method compared with nonlinear equilibrium solutions.

**85-1080**

**Investigation into Wind Effects on Breydon Bascule Bridge**

B. Simpson, D.E. Walshe  
Husband and Co., Caxton St., London SW1H OQP, UK  
Engrg. Struc., Z (1), pp 10-17 (Jan 1985), 9 figs, 2 tables, 5 refs

**KEY WORDS:** Bridges, Wind-induced excitation, Wind tunnel tests

The span is a single leaf bascule bridge linked to an overhead counterweight. During the design process the overhead counterweight arms were investigated. There was a risk of vortex excitation in the fundamental vertical mode; because the arms were tapered, it was difficult to predict this response from previous tests. A 1:20 scale model test in a wind tunnel revealed only weak excitation in the range of design wind speeds. It was concluded that no special precautions need be taken on the full-scale structure.

**85-1081**

**Wind Influence on Kessock Bridge**

A.A.C. Wallace  
Crouch and Hogg, Glasgow, UK  
Engrg. Struc., Z (1), pp 18-22 (Jan 1985), 11 figs, 3 refs

**KEY WORDS:** Bridges, Steel, Wind-induced excitation

This paper describes wind-induced vibrations of a steel deck bridge. Measures adopted to keep the oscillations within acceptable limits are discussed.

**85-1082**

**An Aerodynamic Investigation for the Suspended Structure of the Proposed Tsing Ma Bridge**

D.J. Curtis, J.J. Hart, C. Scruton, D.E. Walshe

Mott Hay and Anderson, 20/26 Wellesley Rd., Croydon, Surrey CR9 2UL, UK  
Engrg. Struc., Z (1), pp 23-33 (Jan 1985), 10 figs, 8 tables, 16 refs

**KEY WORDS:** Suspension bridges, Wind-induced excitation, Flutter, Experimental data

Classical flutter oscillations were a major concern. It was shown that they can be avoided by openings in the lower and upper surfaces of the suspended structure.

## BUILDINGS

**85-1083**

**Analysis for Pressure-Delta Effects in Seismic Response of Buildings**

C.F. Neuss, B.F. Maison  
One Soldiers Field Park No. 401, Boston, MA 02163  
Computers Struc., 12 (3), pp 369-380 (1984), 5 figs, 2 tables, 10 refs

**KEY WORDS:** Multistory buildings, Seismic analysis, Computer-aided techniques

A matrix formulation to account for pressure-delta effects in computer seismic analysis of multistory buildings is presented. The method employs a linear solution approach requiring no iteration and can be used for static or dynamic elastic analyses. Amplified pressure-delta effects resulting from inelastic displacement levels that may occur during a major earthquake can be approximated. The method has been implemented in a computer program. Sample seismic analyses of a 31-story building are presented. Observations on the appropriate use and interpretation of analyses are made.

**85-1084**

**Vibration Monitoring of Large Structures**

C. Williams

Plymouth Polytechnic, Dept. of Civil Engrg., Devon, UK  
Exptl. Tech., 8 (12), pp 29-32 (Dec 1984), 7 figs

**KEY WORDS:** Multistory buildings, Wind-induced excitation, Monitoring techniques

Structures today are susceptible to dynamic disturbing forces. Changes in design and construction techniques require observation of prototype structures to evaluate structural performance and design data. Dynamic testing can provide an overall picture of a structure as well as dynamic characteristics and susceptibility to dynamic loading.

**85-1085**

**Performance of Buildings in the United Kingdom**

N.J. Cook

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Engrg. Struc., 6 (4), pp 248-255 (Oct 1984), 9 figs, 1 table, 11 refs

**KEY WORDS:** Multistory buildings, Wind-induced excitation, Human factors engineering

Damage is categorized by severity, geographical distribution and structural type and is related to meteorological conditions prevailing at the time of failure. Economic aspects are assessed in terms of direct costs of structural repair or replacement but not in terms of loss of service and other structural losses. Deaths and injuries caused by structural failures are compared with those caused directly by wind but not related to buildings. Implications for design practice are given.

**85-1086**

**Case Study of the Dynamic Response of a Medium-Height Building to Wind-Gust Loading**

T.A. Wyatt, G. Best

Imperial College, London SW7, UK

Engrg. Struc., 6 (4), pp 256-261 (Oct 1984), 3 figs, 11 refs

**KEY WORDS:** Multistory buildings, Wind-induced excitation

This paper presents the results of observations of wind-induced motion of a building of relatively modest size and of studies with a mechanical shaker. The investigation confirmed that perceptible motions were to be expected frequently although the building in question had better than average dynamic structural properties. A conventional stochastic model of excitation by gusts appeared adequate. The high response levels were primarily a result of exposure of the site. Implications for designers are discussed.

**85-1087**

**The Prediction of Wind-Induced Responses of the New Hong Kong and Shanghai Banking Corporation Headquarters, Hong Kong**

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Ove Arup & Partners, 15 Fitzroy St., London W1P 6BQ, UK

Engrg. Struc., 2 (1), pp 35-45 (Jan 1985), 15 figs, 6 tables, 8 refs

**KEY WORDS:** Buildings, Wind-induced excitation

Fluctuating aerodynamic forces on a light rigid model of the new building were measured using the force balance technique. The measurements were used to predict overall dynamic response of the building in order to verify the design for strength and to check performance of the building against criteria for deflection, occupant comfort, and fatigue.

**85-1088**

**Wind Induced Damage Observations and Their Implications for Design Practice**

K.C. Mehta

Texas Tech Univ., Lubbock, TX

Engrg. Struc., 6 (4), pp 242-247 (Oct 1984), 13 figs, 14 refs

**KEY WORDS:** Buildings, Wind-induced excitation

A synopsis of wind-induced damage observations is presented. A commentary on damage documentation experiences and remarks on design implications are included. The paper concludes with a discussion of problem areas concerning wind effects and the performance of buildings in windstorms.

## TOWERS

**85-1089**

**Wind Induced Vibrations of Chimneys: The Rules of the CICIND Code for Steel Chimneys**

H. van Koten

Technological Univ., Delft, The Netherlands  
Engrg. Struc., 6 (4), pp 350-356 (Oct 1984), 9 figs, 3 tables, 3 refs

**KEY WORDS:** Chimneys, Wind-induced excitation, Computer programs

Stresses and deflections of 12 existing chimneys in the wind direction were computed. The results were compared with actual behavior of the chimneys. Good agreement verified that the code is sound. Number of load cycles to failure was determined. Estimates of the time in which critical wind-speed can be expected was related to actual experiences with chimneys that have failed. Results compared well.

**85-1090**

**Wind Tunnel Modelling as a Means of Predicting the Response of Chimneys to Vortex Shedding**

B.J. Vickery, A. Daly

The Univ. of Western Ontario, London, Ontario, Canada  
Engrg. Struc., 6 (4), pp 363-368 (Oct 1984), 11 figs, 9 refs

**KEY WORDS:** Chimneys, Vortex shedding, Fluid-induced excitation, Wind tunnel testing

The limitations of wind tunnel testing, particularly for chimneys with a circular cross-section are discussed. Data from full-scale observations and wind tunnel tests at high Reynolds numbers were used with suitable mathematical models to obtain wind load and wind response estimates. These estimates offer a higher level of reliability than wind tunnel estimates.

**85-1091**

**Design Against Wind-Induced Vibration of Multi-Flue Chimney Stacks**

H.Y. Wong, C.R. Heathcock

Univ. of Glasgow, Glasgow G12 8QQ, UK  
Engrg. Struc., 7 (1), pp 2-9 (Jan 1985), 13 figs, 8 refs

**KEY WORDS:** Chimneys, Wind-induced excitation, Design techniques

Instability due to various aerodynamic excitations is possible in multi-flue arrangements. In a sectional configuration with flues and structural members in a pentagonal arrangement, oscillation induced by wind was due to galloping. The amplitude of oscillation increased with increasing in wind velocity. Adding slat devices to the chimneys suppressed galloping oscillation completely. As it is not yet possible to predict the response of a multi-flue chimney stack in wind with any certainty, it is useful to consider means of reducing any oscillatory tendency at the design stage.

**85-1092**

**Dynamics of a Freestanding Steel Lighting Tower**

K.C.S. Kwok, G.J. Hancock, P.A. Bailey, P.T. Haylen

Univ. of Sydney, New South Wales, Australia  
Engrg. Struc., 7 (1), pp 46-50 (Jan 1985), 8 figs, 2 tables, 11 refs

**KEY WORDS:** Towers, Dynamic tests, Damping coefficients, Natural frequencies, Mode shapes

Results of full-scale measurements of the dynamic characteristics of a steel lighting tower are presented. The first three natural frequencies of vibration were found to be 0.50 Hz, 2.40 Hz and 4.84 Hz; corresponding mode shapes were also determined. Results compared well with those obtained from a plane rigid frame dynamic analysis computer program. Damping levels (in % of critical) were approximately 0.3%, 0.8%, and 1.0% for the first three modes.

**85-1093**

**An Assessment of the Sensitivity of Lattice Towers to Fatigue Induced by Wind Gusts**

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Engrg. Struc., 6 (4), pp 262-267 (Oct 1984), 2 figs, 2 tables, 5 refs

**KEY WORDS:** Towers, Wind-induced excitation, Fatigue life

Dynamic properties of lattice towers are constrained by practical economic design. It is possible to generalize the prediction of dynamic response using a stochastic wind gust model. An approximation to the combined effect of resonant and non-resonant components of response is presented. It is applied to the effective stress range based on the dynamic response computed at reference wind speed. Results presented for a range of practical structures indicate that good detailing can generally ensure that fatigue damage caused by wind gusts does not seriously limit design. Sensitivity of normalized results to changes of location and of tower function and geometry is relatively small.

**85-1094**

**Dynamic Behaviour of Transmission Towers: Field Measurements**

J.J. Jensen, G. Folkestad

Cement and Concrete Res. Inst., SINTEF Div. FCB, Trondheim, Norway

Engrg. Struc., 6 (4), pp 288-296 (Oct 1984), 10 figs, 4 tables, 17 refs

**KEY WORDS:** Towers, Wind-induced excitation, Fatigue life

Comparison of measurements with analytical work is useful in evaluating design specifications of tower structures. Examples of general dynamic behavior and information about design parameters to be used in analysis of such structures are given. Inspections and control systems to detect structural irregularities and evaluate fatigue damage are described.

**85-1095**

**Modelling of Wind Loads with Regard to Gust Effects**

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Engrg. Struc., 6 (4), pp 274-280 (Oct 1984), 8 figs, 8 refs

**KEY WORDS:** Cooling towers, Buildings, Wind-induced excitation

This paper reviews the suitability of various wind loading concepts for estimating peak response produced in buildings by wind turbulence. A quasi-static model is described and applied to cooling towers. It assures close agreement with measured response.

**85-1096**

**Calculation of the Effect of a Resilient Seating on the Vibration Characteristics of Slender Structures**

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Engrg. Struc., 6 (4), pp 307-314 (Oct 1984), 8 figs, 6 refs

**KEY WORDS:** Chimneys, Base isolation, Elastomeric dampers, Natural frequencies, Mode shapes

A general dynamical model of a vertical slender structure with damping is derived. The model can be used to calculate frequencies, logarithmic decrements and mode shapes for the free vibration of a structure. The model is used to analyze a chimney mounted on a resilient seating to increase damping. Typical results are given.

**85-1097**

**The Efficiency of Helical Strakes for the Suppression of Vortex-Excited Oscillation of Steel Stacks**

H. Ishizaki, H. Hara, T. Shimada  
Disaster Prevention Res. Inst., Kyoto Univ., Japan  
Engrg. Struc., 6 (4), pp 334-339 (Oct 1984), 14 figs, 1 table, 6 refs

**KEY WORDS:** Chimneys, Steel, Wind-induced excitation, Vibration control

Helical strakes are used to suppress vortex-excited oscillation of stacks. Wind-tunnel experiments on two-dimensional models were performed to reconsider the optimum configuration of the strakes. Based on the results, the effectiveness of the strakes was confirmed by experiments on an actual stack. The stack with strakes was more economical than the plain stack without strakes.

**85-1098**

**Steel Chimney Oscillations: A Comparative Study of Their Reported Performance Versus Predictions Using Existing Design Techniques**

B.N. Pritchard  
Esso Engineering (Europe) Ltd., New Malden, Surrey, UK  
Engrg. Struc., 6 (4), pp 315-323 (Oct 1984), 9 figs, 1 table, 17 refs

**KEY WORDS:** Chimneys, Steel, Wind-induced excitation

The chimneys vary in height between 23m and 145m. None was fitted with helical spoilers or other damping devices. The

study showed that techniques based on mass damping parameters give the best correlation, but none could be regarded as satisfactory. A newly developed empirical parameter appears to improve correlation with reported performance. This non-dimensional parameter incorporates mass damping and stiffness properties. The paper does not attempt to develop any theoretical explanation for the better correlation given by the new parameter.

**85-1099**

**The Response of Reinforced Concrete Chimneys to Vortex Shedding**

B.J. Vickery, R.L. Basu  
The Univ. of Western Ontario, Faculty of Engrg. Science, London, Ontario, Canada  
Engrg. Struc., 6 (4), pp 324-333 (Oct 1984), 15 figs, 1 table, 14 refs

**KEY WORDS:** Chimneys, Reinforced concrete, Vortex shedding, Wind-induced excitation

Predicted vortex-induced response of reinforced concrete structures of circular cross-section is compared with full-scale behavior. On average predictions and observations agree to within 5%. The large scatter is attributable to failure of the model to recognize the dependence of aerodynamic parameters on free stream turbulence. The high coefficient of variation of the model does not markedly differ from that associated with prediction of drag loads.

**85-1100**

**Problems with In-Line Stacks: Experience with Full-Scale Objects**

H. Ruscheweyh  
Institut für Leichtbau, Aachen Technical Univ., Aachen 5100, W. Germany  
Engrg. Struc., 6 (4), pp 340-343 (Oct 1984), 10 figs, 7 refs

**KEY WORDS:** Chimneys, Steel, Wind-induced excitation, Fatigue life

Three examples of problems encountered with wind-induced excitation of in-line stacks are discussed. Various dampers are described. Practical considerations of turning and fatigue are considered.

## FOUNDATIONS

85-1101

### Experimental Studies of Dynamic Response of Foundations

B. Hushmand

Ph.D. Thesis, California Inst. of Technology, 317 pp (1984), DA8420814

KEY WORDS: Foundations, Soil-foundation interaction

The investigation was aimed at studying both low and high amplitude vibrations of foundations under machine type loadings, earthquake, wave-induced vibrations, and other sources of dynamic loads. The effect of soil depth, boundary conditions, and depth of foundation embedment were investigated. Rocking and horizontal modes of vibration were studied. Experimental results provided information regarding influences of geometrical, inertial, and loading conditions on the vibrational characteristics of the soil-structure system.

## POWER PLANTS

85-1102

### Vibration Analysis of a Pool Type LMFBR. Comparison Between Calculation and Full Scale Test Results

S. Aita, F. Gantenbein, Y. Tigeot, C. Bertaut

CEA Centre d'Etudes Nucleaires de Saclay, Gif-sur-Yvette, France

Rept. No. CEA-CONF-6994, CONF-8308-05-69, 11 pp (Aug 1983), DE84750717

KEY WORDS: Nuclear reactors, Fluid-induced excitation

A full-scale test program on SUPERPHENIX 1 Reactor has been defined. This paper concerns the first step of the program and presents a three dimensional in-air calculation procedure and results, air test procedure and results, and a comparison between calculation and tests results. This comparison is different for the two main structures studied and depends on the nature and complexity of the respective modes. Various aspects of calculation are validated; guidelines for additional tests are given.

85-1103

### Physical Models and Numerical Methods of the Reactor Dynamic Computer Program RETRAN

G. Kamelander, F. Woloch, G. Sdouz, H. Koinig

Oesterreichisches Forschungszentrum Seibersdorf, GmbH Inst. fuer Reaktorsicherheit Rept. No. OEFZS-4272, RS-235/84, 52 pp (Mar 1984), N84-28587 (In German)

KEY WORDS: Nuclear reactors, Numerical analysis, Computer programs

Physical models and numerical methods of a reactor code simulating reactivity transients in light water reactors are described. The neutron physical part is based on two group-diffusion equations that are solved by discretization. An exponential transformation was applied. Inner iterations were accelerated by a coarse mesh rebalancing procedure. The thermohydraulic model approximates the equation of state by a built-in steam-water table.

85-1104

### Technology Development on Seismic Analysis of Nuclear Reactor Structure

E.H. Kwak, D.H. Kim, Y.S. Kim, U.Y. Cho

Korea Advanced Energy Res. Inst., Seoul, Korea

Rept. No. KAERI/RR-361/82, 123 pp (1983), DE84700099 (In Korean)

KEY WORDS: Nuclear power plants, Seismic analysis, Soil-structure interaction

The object of this study was to evaluate structures, systems and components in nuclear power plants for seismic safety using soil-structure interaction analysis. Computer codes "TIGEN" and "SUPRES" were used to generate artificial time histories. "SAP V" and "ELUSH" codes were used to assess dynamic characteristics of mathematical model for the building and structures. A modified "SPECTR" code was used to generate floor design response spectra that will be used for seismic qualification.

85-1105

**Uncertainty in Soil-Structure Interaction Analysis of a Nuclear Power Plant Due to Different Analytical Techniques**

J.C. Chen, R.C. Chun, G.L. Goudreau, O.R. Maslenikov

Lawrence Livermore National Lab., CA  
Rept. No. UCRL-90029, CONF-8480703-1, 14 pp (1984),  
DE84003727

**KEY WORDS:** Nuclear power plants, Soil-structure interaction, Substructuring methods, Finite element technique

This paper summarizes results of a dynamic response analysis of the Zion reactor containment building. Three different soil-structure interaction (SSI) analytical procedures were used. They are: the substructure method, CLASSI; the equivalent linear finite element approach, ALUSH; and the nonlinear finite element procedure, DYNA3D. Uncertainties in analyzing a soil-structure system due to SSI analysis procedures were investigated. Responses at selected locations in the structure were compared using accelerations and response spectra.

## VEHICLE SYSTEMS

### GROUND VEHICLES

85-1106

**Identification Methods for Vehicle Dynam-**

**ics (Identifikationsmethoden für die Fahrdynamik)**

W. Reichelt

Institute of Vehicle Dynamics, Tech. Univ. Braunschweig, Fed. Rep. Germany  
Automobiltech. Z., 86 (9), pp 391-397 (Sept 1984), 9 figs, 16 refs (In German)

**KEY WORDS:** Ground vehicles, System identification techniques, Time domain method, Frequency domain method

Different identification methods in the time and frequency domains were tested for their suitability in evaluating yaw-transfer functions of motor vehicles with different driving qualities. Influences of input signals, step pulse, and random input were examined. A method of excitation employing random input is described. The yaw-transfer functions that used random input (frequency domain) showed the best agreement with the actual transfer functions of the motor vehicles tested. Results of a comparison among three methods of identification for application to vehicle dynamics are given.

85-1107

**Modern Fatigue Data for Dimensioning Vehicle Components Made of Ductile and Malleable Cast Irons - Part 2**

M. Huck, W. Schutz, H. Walter

Industrieanlagen-Betriebsgesellschaft (IABG), Ottobrunn, Fed. Rep. Germany  
Automobiltech. Z., 86 (9), pp 385-388 (Sept 1984), 19 figs, 33 refs (In German)

**KEY WORDS:** Fatigue tests, Structural members, Automobiles, Experimental data

Results of tests on malleable cast iron GTS 55 and ductile iron with the standard grades GGG 40, GGG 60, and GGG 80 provide design data for fatigue-loaded components made of those materials. Part 2 contains the result of tests under variable amplitudes; in the appendix the results and relationships are described in mathematical form.

85-1108

**Wheel-Rail Contact Wear, Work, and Lat-**

**eral Force for Zero Angle of Attack — A Laboratory Study**

S. Kumar, D.L.P. Rao

Illinois Inst. of Tech., Chicago, IL 60616

J. Dynam. Syst., Meas. Control, Trans.

ASME, 106 (4), pp 319-326 (Dec 1984), 14 figs, 2 tables, 18 refs

**KEY WORDS:** Rail-wheel interaction, Wear

An analysis of a wheel/rail interaction as a two-point contact problem is presented. To establish the validity of the theory and applicability of the indices, results from a series of four experiments on a quarter scale laboratory rig are reported. It is concluded that lateral forces should be explicitly included in wear index formulation. It is also concluded that the wear-work principle as formulated in the paper can be considered reasonably valid.

**85-1109**

**Control Law Design and Dynamic Evaluations for a Maglev Vehicle with a Combined Lift and Guidance Suspension System**

W. Kortüm, A. Utzt

DFVLR, Inst. for Flight Systems Dynamics, D-8301 Weßling, Fed. Rep. Germany

J. Dynam. Syst., Meas. Control, Trans.

ASME, 106 (4), pp 286-292 (Dec 1984), 12 figs, 12 refs

**KEY WORDS:** Ground effect machines, Magnetic suspension techniques

The magnetically levitated vehicle (MAGLEV) control law design based on design models and dynamic simulations with evaluation models are treated. It is demonstrated that it is possible to design the control law from a vertical model only. The control design is performed by quadratic synthesis (RICCATI design). Dynamic evaluations show that the strategy yields good results. The lateral response - not considered in the design - due to wind gusts is well damped. The vertical response due to track irregularities and track flexibility is stable.

**AIRCRAFT**

**85-1110**

**A Study of Crashworthiness of Light Aircraft Fuselage Structures: A Numerical and Experimental Investigation**

A.P. Nanyaro

Ph.D. Thesis, Univ. of Toronto (Canada), (1984)

**KEY WORDS:** Crash research (aircraft), Finite element technique, Computer programs, Experimental data

A cost-effective computer code is based on a consistent finite element (CFE) approach. It provides reasonably accurate estimates of g-loads, dynamic strains, and transient collapse modes. Comparisons with a simpler numerical model indicate that more accurate predictions can be obtained from CFE analysis at comparable computing costs.

**85-1111**

**Experimental Modal Analysis of a Partial Full-Scale Fuselage of Turboprop Aircraft (Analisi Modale Sperimentale di UN Tronco di Fusoliera di UN Velivolo Turboprop)**

A. Paonessa, S. Mandarini, L. Lecce, F. Marulo

Aeritalia S.p.A., Naples, Italy

17 pp (1983)(Presented at 7th Assoc. Ital. Di Aeron. E. Astron. Congr. Nazi. Sulla Base Dell'Esame Del Solo Sommario, Naples, pp 25-28 (Oct 1983), N84-27732 (In Italian)

**KEY WORDS:** Aircraft, Experimental modal analysis

This vibro-acoustic test program to study cabin noise reduction technology was based on a modal analysis. A single input frequency response function method was used to perform the analysis in an ATR-42 aircraft. The test program includes three measurement configurations for a total of 182 pickups. Frequency ranges up to 500 Hz, with and without a 5 PSI pressurization were used. Principal modes related either to the global structure or to its parts

(frame, stringer, and skin-panel) were identified.

**85-1112**

**Measurement of Transonic Dips in the Flutter Boundaries of a Supercritical Wing in a Wind Tunnel**

A.J. Persoon, J.J. Horsten, J.J. Meijer  
National Aerospace Lab., Amsterdam, The Netherlands

J. Aircraft, 21 (11), pp 906-912 (Nov 1984), 12 figs, 5 refs

**KEY WORDS:** Aircraft wings, Flutter, Measurement techniques

Flutter experiments were performed on a supercritical transport-type wing to investigate the transonic dip in flutter boundaries. Data for verification of a calculation method for unsteady aerodynamic loads were obtained. Complete transonic dips were measured at three angles of attack. At the highest angle a second dip was found. A mean pressure distribution measured in one chordwise section could explain flutter characteristics. A flutter damper device was used to measure flutter onset accurately and rapidly. The experimental test setup, on-line data reduction, and results are given.

**85-1113**

**Bending Effects on Structural Dynamic Instabilities of Transonic Wings**

N.D. Malmuth, S.R. Chakravarthy, J.D. Cole, T.P. Goebel  
Rockwell International Science Ctr., Thousand Oaks, CA

J. Aircraft, 21 (11), pp 913-920 (Nov 1984), 13 figs, 15 refs

**KEY WORDS:** Aircraft wings, Flutter, Flexural vibrations

Nonclassical flutter was idealized as the lift-induced forced oscillation of a cantilever beam simulating the wing. Strip theory was used with a suitably revised version of LTRAN2 to supply aerodynamic input. The resulting time integration algo-

rithm provides a procedure to determine the destabilizing effects of sweepback. Computations with the method closely predict flutter frequencies in two out of three cases. For the third case, damped oscillations are predicted rather than amplified ones observed. Reasons for the discrepancy involve the second bending mode. Recommendations for refinements of the procedure concern inclusion of modal coupling and analysis of limit cycle aspects and three-dimensional phenomena.

**85-1114**

**A Vortex-Lattice Method for General, Unsteady Aerodynamics**

P. Konstadinopoulos, D.F. Thrasher, D.T. Mook, A.H. Nayfeh  
Virginia Polytechnic Inst. and State Univ., Blacksburg, VA

J. Aircraft, 22 (1), pp 43-49 (Jan 1985), 14 figs, 1 table, 18 refs

**KEY WORDS:** Aircraft wings, Aerodynamic loads, Fluid-induced excitation

A general method for calculating unsteady, incompressible, inviscid, three-dimensional flows around arbitrary planforms has been developed. The method is an extension of the vortex-lattice technique. It is not limited by aspect ratio, camber, or angle of attack, as long as vortex breakdown does not occur above the wing surface and separation occurs only along sharp edges. As the wing performs arbitrary maneuvers, position of the wake and distribution of circulation on the wing and in the wake are obtained as functions of time. One desirable feature of the method is its ability to efficiently treat steady lifting flows. Examples of steady and unsteady flows include rectangular wings with and without flaps, and delta and cropped delta wings.

**85-1115**

**Active Control of Forward Swept Wings with Divergence and Flutter Aeroelastic Instabilities**

K.E. Griffin

Ph.D. Thesis, Air Force Inst. of Technology, 150 pp (1984), DA8425340

**KEY WORDS:** Aircraft wings, Flutter, Active vibration control

A study is made of simple active control laws to suppress aeroelastic flutter and divergence on forward-swept advanced composite wings. The analysis method uses root locus plots of characteristic roots from transformed equations of motion to determine aeroelastic stability of each feedback-controlled configuration. The leading-edge flap and elastic displacement sensing seem to be the best technique for controlling divergence speed of forward-swept wings. If the structural designer provides high flutter speeds for an uncompensated wing before applying active control, a better wing design may be available for active control divergence.

**85-1116**

**Steady and Unsteady Transonic Airloads on a Supercritical Wing**

S.Y. Ruo, J.B. Malone, J.J. Horsten, R. Houwink  
Lockheed-Georgia Co., Marietta, GA  
J. Aircraft, 22 (1), pp 28-36 (Jan 1985), 16 figs, 14 refs

**KEY WORDS:** Aircraft wings, Aerodynamic excitation, Computer programs

An experimental investigation to determine steady and unsteady airloads on a fixed and an oscillating supercritical wing model is presented. Steady and unsteady data are correlated with results of computational methods for various cases. Steady transonic flow computations were carried out using the XTRAN3S code and the Bailey-Ballhaus/McNally code. Unsteady flow computations were performed using the XTRAN3S code and a quasi-three-dimensional method that combines the LTRAN2-NLR code with subsonic theory. Compared to experimental data computed results show qualitatively similar transonic effects on pressure distributions and lift coefficients. Accuracy is modest.

**85-1117**

**Aerodynamic Characteristics of an Airfoil in a Nonuniform Wind Profile**

F.M. Payne, R.C. Nelson

Univ. of Notre Dame, Notre Dame, IN  
J. Aircraft, 22 (1), pp 5-10 (Jan 1985), 16 figs, 16 refs

**KEY WORDS:** Airfoils, Aerodynamic loads, Wind-induced excitation, Wind tunnel testing

An experimental wind tunnel investigation was carried out to determine the influence of a nonuniform wind profile on the static longitudinal aerodynamic coefficients of an airfoil. Force balance and surface pressure measurements were obtained from an NACA 0018 airfoil in a linear velocity gradient. The airfoil was tested in a Reynolds number range. Endplates simulated an infinite wing; the outboard endplate was removed to simulate a finite wing. The effect of grit on the surface of the airfoil was also investigated. Influence of the velocity gradient on aerodynamic characteristics of the airfoil was small, especially in comparison to the effects of grit.

**85-1118**

**Airport Noise Monitoring Systems in North America**

C.R. Bragdon  
S/V, Sound Vib., 18 (12), pp 20-21 (Dec 1984), 1 table, 5 refs

**KEY WORDS:** Airports, Aircraft noise, Noise measurement

There are 26 noise monitoring systems at North American airports. Reasons include compliance with enacted regulations or standards. The systems consist of four basic components: remote monitoring systems, central processing stations, software, and accessories. It is anticipated that the number of such systems will increase.

**85-1119**

**Preliminary Experimental and Theoretical Results on Cantilever Vibration Absorbers Applied for Aircraft Cabin Vibration**

L. Lecce, F. Marulo, E. Ferrante  
Inst. di Progetto Velivoli, Naples Univ., Naples, Italy

Rept. No. SPER-8390, 77 pp (1983), N84-27730 (In Italian)

**KEY WORDS:** Aircraft noise, Interior noise, Noise reduction, Dampers

The design and calculation of vibrating beam dampers for aircraft cabin noise reduction are investigated. A calculation method to evaluate the efficiency of dampers applied to panels of simple shape and boundary conditions is presented. Results of experiments in which cantilever dampers were adapted to aluminum alloy panels are presented. The resonant frequency estimation errors vary from 5% to 15% for different types of vibrating beams. A theoretical approach to computation of dynamic response of pressurized cabins with dampers tuned to the fundamental aircraft propeller frequency is proposed.

**85-1120**

**Flight Study of Induced Turbofan Inlet Acoustic Radiation with Theoretical Comparisons**

J.S. Preisser, R.J. Silcox, W. Eversman, A.V. Parrett  
NASA Langley Res. Ctr., Hampton, VA  
J. Aircraft, 22 (1), pp 57-62 (Jan 1985), 15 figs, 10 refs

**KEY WORDS:** Aircraft engines, Noise generation, Sound waves, Wave radiation

This paper presents a study of acoustic tone radiation patterns from a small turbofan engine in flight. Results are compared with similar static test stand data and a recently developed radiation theory. An interaction tone was induced for test and evaluation purposes. Overhead and sideline flight directivity patterns showed cut-on of a dominant single-mode tone occurred at the predicted fan speed. There were no other significant circumferential or radial modes. In general, good agreement was found between measured flight and static data. Small differences were attributed to inlet geometry and forward speed effects. Good agreement was also obtained between flight data and theory for directivity pattern shape.

**85-1121**

**Propagation of Propeller Tone Noise Through a Fuselage Boundary Layer**

D.B. Hanson, B. Magliozzi  
Hamilton Standard, Windsor Locks, CT  
J. Aircraft, 22 (1), pp 63-70 (Jan 1985), 11 figs, 1 table, 15 refs

**KEY WORDS:** Aircraft propellers, Noise generation

A new three-dimensional theory is described that treats the combined effects of refraction and scattering by the fuselage and boundary layer. The complete wave field is solved by matching analytical expressions for incident and scattered waves in the outer flow to a numerical solution in the boundary-layer flow. The model for the incident waves is a near-field frequency-domain propeller source theory developed previously for free-field studies. Calculations for an advanced turboprop (pro-fan) model flight test at a Mach number of 0.8 show a much smaller-than-expected pressure amplification at the noise directivity peak. Strong boundary-layer shielding in the forward quadrant and shadowing around the fuselage occurred. Results show the difference between fuselage surface and free-space noise predictions as a function of frequency and Mach number. Comparison of calculated and measured effects obtained in a prop-fan model flight test shows good agreement.

**MISSILES AND SPACECRAFT**

**85-1122**

**Component Vibration Environment Predictor**

F. Spann, P. Patt  
The Boeing Aerospace Co., Seattle, WA  
J. Environ Sci., 22 (5), pp 19-24 (Sept/Oct 1984), 14 figs, 2 refs

**KEY WORDS:** Spacecraft components, Vibration prediction, Environment simulation, Computer programs

This paper presents a vibration prediction method requiring only a general description of the hardware design. The method pro-

vides a reasonable estimate of acoustically-excited component vibration environments when only the area exposed to the acoustic environment and weight are known. Use of the method, theoretical background, evaluation of prediction accuracy, and a description of a vibration predictor computer program are presented.

**85-1123**

**Shock Absorbing Missile Launch Pad**

G.E. Rudd

Dept. of Air Force, Washington, D.C.

U.S. Patent Appl. No. 6-614 905, 45 pp (May 1984)

**KEY WORDS:** Missile launchers, Shock absorbers, Elastomers

Shock absorbing missile launch pad for Mx type missiles have molded ethylene propylene diene terpolymer composition. Pad has curved resilient rubber pad with a Teflon-fiberglass laminate bonded to outer convex surface. A support plate is bonded to the inner concave surface. Springs urge pad away from missile at launch to prevent damage to missile.

**85-1124**

**Influence of High Angle of Attack Flow Phenomena on the Dynamic Stability of Slender Missiles**

J.M. Jenista, R.C. Nelson

Univ. of Notre Dame, Notre Dame, IN

Rept. No. AFATL-TR-83-4, SBI-AD-E800 971, 73 pp (Jan 1983), AD-A143 185

**KEY WORDS:** Missiles, Vortex-induced vibration

The purpose of this study was to better understand the influence of separated wake flows on vehicle dynamic stability. The body vortex wake flow was mapped around several slender missile configurations using two flow visualization techniques. One used a laser-produced sheet of light that illuminated smoke passing around the model. The other used neutrally buoyant helium-filled soap bubbles as flow tracers.

Models were tested at angles of attack from 15 to 55 degrees, at subcritical Reynolds numbers and for free-stream turbulence levels of 0.1 to 0.8 percent.

**85-1125**

**Sound Generation by Turbulence in Simulated Rocket Motor Cavities**

U.G. Hegde, W.C. Strahle

Georgia Inst. of Technology, Atlanta, GA

AIAA J., 23 (1), pp 71-77 (Jan 1985), 11 figs, 9 refs

**KEY WORDS:** Solid propellant rocket engines, Sound generation, Turbulence

The investigation is motivated by vibration problems in solid-propellant rocket motors. Interior flows modeled to simulate flow conditions inside rocket motor cavities are considered. The turbulence generated pressure fluctuation consists of two components, acoustic and hydrodynamic. The Bernoulli enthalpy theory of aeroacoustics is employed to extract acoustic pressure spectra from experimentally obtained turbulence data and acoustic impedance values at flow boundaries. Effects of turbulence intensities, sidewall acoustic impedance, length-to-diameter cavity ratio, and different mass flux on the acoustic pressure level are investigated. Typical pressure levels inside rocket motor environments are calculated utilizing the A-B representation for propellant response.

## BIOLOGICAL SYSTEMS

### HUMAN

**85-1126**

**Experimental and Calculating Investigation of the Elements of Man-Made Heart Valves Under Static and Dynamic Loads**

S. Kisilev, A. Gazarian, V. Kniazev, O. Naraykin

Moskovskoe visshie tekhnicheskoe utchilishche im. N.E. Bauman, USSR

Vibrotechnika, 1 (41), pp 17-28 (1983), 7 figs, 7 refs (In Russian)

**KEY WORDS:** Organs (biological), Biomechanics, Design techniques

A method for calculating the strength, stiffness, and vibrations of the elements of an artificial heart valve is given. Results of experiments and tests are presented. The solution of the static and dynamic problems allows selection of appropriate geometrical sizes and materials for the valves and excludes resonance conditions in the system.

## MECHANICAL COMPONENTS

### ABSORBERS AND ISOLATORS

**85-1127**

**Random Vibration and Optimization of Design of Aseismic Base Isolation Systems**  
M.C. Constantinos  
Ph.D. Thesis, Rensselaer Polytechnic Inst., 213 pp (1984), DA8426511

**KEY WORDS:** Base isolation, Seismic design, Elastomeric bearings

This thesis studies the random vibration and optimization of design of base isolation systems. Random vibration is important both in optimization studies and risk assessment. Only the former is considered. The overall conclusion is that base isolation is very effective. It is affected by the fundamental frequency of the structure and by the frequency content of the stochastic seismic excitation. Most effective are systems that use special dampers of hysteretic nature.

**85-1128**

**Experiments on Sound-Absorbing Shaw-Type Horns with Spatially Varying Effective Density**

B.N. Nagarkar, R.D. Finch  
Univ. of Houston, Houston, TX 77004  
J. Acoust. Soc. Amer., 77 (1), pp 48-53 (Jan 1985), 15 figs, 4 refs

**KEY WORDS:** Mufflers, Horns (sound generators), Variable material properties  
Acoustic absorption

An experimental investigation of Shaw's theory of sound propagation in acoustic horns with spatially varying density and elasticity is reported. The density-variation technique was used to simulate a conical horn in a tube of uniform cross section using perforated sheet metal plates. Performances of the density variation horn and an equivalent conical horn were evaluated. The density-variation conical horn had sound-absorbing properties due to the perforated plates. It can thus be used as a muffler. A muffler was designed and its performance evaluated using both a loudspeaker and an internal combustion engine as sound sources.

**85-1129**

**Theory of Vibration Isolation of a System with Two Degrees of Freedom (1st Report, Motion Excitation)**

H. Sekiguchi, T. Asami  
Himeji Inst. of Technology, 2167, Shosha, Himeji, Hyogo, 671-22, Japan  
Bull. JSME, 27 (234), pp 2839-2846 (Dec 1984), 15 figs, 5 refs

**KEY WORDS:** Dynamic vibration absorption (equipment)

This paper deals with a theory of vibration isolation of a two-degree-of-freedom system subjected to harmonic motion. Each subsystem has one degree of freedom. The first subsystem consists of a mass connected to a foundation in motion through a spring and a dashpot in parallel. The second contains a mass, a spring, and a dashpot and is attached to the first mass. The problem of two dashpots remains unsettled. The optimum suspension was sought for vibration isolation of the two masses of the system.

**85-1130**

**Dynamic Axial Crushing of Circular Tubes**  
W. Abramowicz, N. Jones

The Univ. of Liverpool, P.O. Box 147,  
Liverpool L69 3BX, UK  
Intl. J. Impact Engrg., 2 (3), pp 263-281  
(1984), 11 figs, 2 tables, 22 refs

**KEY WORDS:** Energy absorption, Compressive strength, Cylindrical shells

A series of axial crushing tests on steel circular cylindrical shells loaded either statically or dynamically is reported. Results are compared with various theoretical predictions and empirical relations. A modified version of Alexander's theoretical analysis for axisymmetric deformations gives good agreement with experimental results. The effective crushing distance must be considered. The influence of material strain rate sensitivity must be retained in the dynamic crushing case.

**85-1131**

**Dynamic Axial Crushing of Square Tubes**

W. Abramowicz, N. Jones

The Univ. of Liverpool, P.O. Box 147,  
Liverpool L69 3BX, UK  
Intl. J. Impact Engrg., 2 (2), pp 179-208  
(1984), 23 figs, 4 tables, 30 refs

**KEY WORDS:** Compressive strength, Tubes, Dynamic tests, Experimental data

Eighty-four dynamic tests on thin-walled square steel tubes having two different cross sections and various lengths were crushed axially on a drop hammer rig. Approximate theoretical predictions were developed for the axial progressive crushing of square box columns. A kinematically admissible method of analysis was used. New asymmetric deformation modes were predicted theoretically and confirmed in experimental tests. The effective crushing distance is considered in the approximate theoretical analysis. The influence of material strain rate sensitivity is also considered.

**85-1132**

**Analysis of a System with Non-Linear Damping**  
A. Tondl

National Res. Inst. for Machine Design,  
Praha-Bechovice, CSSR  
Strojnický Časopis, 35 (5), pp 563-570  
(1984), 7 figs, 2 refs (In Czech)

**KEY WORDS:** Shock absorbers, Damping coefficients

An Analysis is presented of the action of a hydraulic shock absorber whose intensity decreases when a certain limit deflection is exceeded. The aim of the study is to explain the hysteresis phenomenon due to dwell and the hysteresis loop in the force-velocity diagram.

## **TIRES AND WHEELS**

**85-1133**

**Study on the Mechanism of Noise Generation from Railway Wheel and Its Countermeasures (6th Report, Noise Reduction by a Damped Wheel)**

S. Sato, H. Matsuhisa, N. Ohira

Kyoto Univ., Sakyo-ku, Kyoto, Japan  
Bull. JSME, 27 (234), pp 2857-2862 (Dec 1984), 9 figs, 3 tables, 7 refs

**KEY WORDS:** Railway wheels, Noise generation, Rail-wheel interaction, Elastomeric dampers

Vibration and noise of a damped wheel are investigated theoretically and experimentally. A dynamic damper composed of a rubber and a steel thin annular plate is attached to the web of a conventional wheel. The rubber is assumed to be a spring with viscous damping. Vibration and noise can be considerably reduced by the dynamic damper. When the fundamental frequency of the dynamic damper equals the natural frequency of the wheel, the vibration is remarkably decreased. Effective reduction of vibration and noise requires that the rubber have a large loss factor and that the damper is attached to the outer side of the wheel.

## BLADES

85-1134

### Noise Reduction on the Centrifugal Suction Fan of a Berlin Street Sweeper Truck

W. Neise, G.H. Koopmann

DFVLR-Institut für Turbulenzforschung, Berlin, W. Germany

Noise Control Engrg. J., 23 (2), pp 78-88 (Sept/Oct 1984), 16 figs, 5 refs

**KEY WORDS:** Blade passing frequency, Noise reduction, Fans, Centrifugal forces

The method reduced the blade passing frequency noise of the centrifugal suction fan of a street sweeper truck. A new inlet nozzle at the impeller eye and a short splitter plate in the inlet box improved fan performance. A tuneable, acoustic, double resonator mounted in the cutoff of the fan casing diminished sound pressure level at the blade passing frequency. The modifications allowed the original fan speed to be lowered. Fan efficiency also improved and less fuel was burned. Reductions in the total A-weighted noise and in the blade passing frequency sound pressure level occurred.

85-1135

### Wind-Induced Failure of Wind Turbines

P.H. Madsen, S. Frandsen

Meteorology Section, Physics Dept., Riso National Lab., DK-4000 Roskilde, Denmark  
Engrg. Struc., 6 (4), pp 281-287 (Oct 1984), 7 figs, 3 tables, 16 refs

**KEY WORDS:** Wind turbines, Wind-induced excitation, Fatigue life, Turbine blades

Models of loading and structural behavior for use in lifetime prediction of propeller type wind turbines are discussed. Emphasis is on wind-induced loads. Turbulence is represented by auto-cross-spectra of turbulent wind speed fluctuations. Structural response is calculated in the frequency domain. Stress responses appear as a combined periodic and stochastic signal. A fatigue model and a simple approach to extreme response calculations account for

both periodic and stochastic parts of the stress response. Results with the model are compared with measured data.

## BEARINGS

85-1136

### Rolling Bearings for Hostile Environments

A.G. Herraty, J.C.M. Bras

SKF Engrg. and Res. Ctr., B V, The Netherlands

Chart. Mech. Engrg., 31 (11), pp 42-43 (Nov 1984), 2 figs, 2 refs

**KEY WORDS:** Roller bearings, Environmental effects, Design techniques

This article describes two design philosophies pursued by SKF to obtain an optimum service performance in hostile environments.

85-1137

### Dynamic Stiffness Characteristics of High Eccentricity Ratio Bearings and Seals by Perturbation Testing

D.E. Bently, A. Muszynska

Bently Nevada Corp., Minden, NV 89423

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 481-501, 10 figs, 11 refs

**KEY WORDS:** Bearings, Seals, Stiffness coefficients, Eccentricity, Perturbation theory

This paper has to do with the behavior of cylindrical bearings and seals that are statically loaded to eccentricities in excess of 0.7. The stiffness algorithms as a function of static load are developed from perturbation methodology by empirical modeling.

85-1138

### Separator Contact Location in Angular Contact Ball Bearings

L.J. Nypan  
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91330  
Lubric. Engrg., 40 (12), pp 738-743 (Dec  
1984), 7 figs, 6 refs

**KEY WORDS:** Ball bearings, Contact vibration

Photographs over many revolutions of a ball-bearing separator were measured. The distance between separator and ball bearing inner race were plotted as a function of position within the bearing. The location of the cage to inner-race contact variation over several revolutions can be identified and related to the resultant of ball-to-separator contact forces.

85-1139  
**Stiffness and Damping Coefficients of Spherical Spiral Grooved Bearings**  
N. Kawabata, Y. Miyake  
Fukui Univ., Bunkyo 3-9-1 Fukui, Japan  
Trib. Intl., 17 (5), pp 259-267 (Oct 1984),  
11 figs, 9 refs

**KEY WORDS:** Bearings, Stiffness coefficients, Damping coefficients

Dynamic characteristics of a spherical spiral groove bearing were analyzed using a narrow groove hypothesis for incompressible fluid film and isothermal gas film. The usefulness of the method is demonstrated by comparing results with those obtained using established methods. The method is efficient for optimization design and other analysis problems. The influences of bearing parameters and of compressibility of fluid on dynamic performance and stability are presented.

85-1140  
**Design of Electromagnetic Bearing for Vibration Control of Flexible Transmission Shaft**  
V. Gondhalekar, R. Holmes  
E.T.H. Zurich, Switzerland  
Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of

Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 351-363, 8 figs, 3 refs

**KEY WORDS:** Electromagnetic bearings, Vibration control

This paper is concerned with the design and construction of a bearing with new features. They include an original approach to the design of electromagnets and their amplifiers. Control signals are conditioned with software so as to make the magnets appear to be linear and uncoupled. The resulting system is used to control a rotor-bearing assembly, the speed range of which covers two flexural-critical speeds.

## COUPLINGS

85-1141  
**Give the Shaft to Flexible Coupling Problems**  
T.R. Dombrowski  
S.S. White Industrial Products Div., Pennwalt Corp., Piscataway, NJ  
Power Transm. Des., 26 (10), pp 29-32 (Oct 1984), 4 figs, 2 tables

**KEY WORDS:** Flexible couplings, Flexible rotors

Transmitting power from point A to point B can be complicated. Universal joints, gearboxes, or offset pulleys are required to get the job done. A rotary motion flexible shaft (RMFS) can often uncomplicate the design and reduce the number of components needed.

## FASTENERS

85-1142  
**Application of Swivel Hinges as Swivel Joints for Small Vibration Angles (Einsatz von Schwenkgelenken als Drehgelenke für kleine Schwingwinkel)**  
A. Fricke

Technische Hochschule Karl-Marx-Stadt,  
Sektion Maschinen-Bauelemente, German  
Dem. Rep.  
Maschinenbautechnik, 33 (9), pp 419-422  
(1984), 5 figs, 1 table, 10 refs (In German)

**KEY WORDS:** Joints, Plates

The swivel hinge is a material-paired, backlash-free hinge for oscillatory motions with a small amplitude. Based on linear plate theory statements are made about the load capacity of hinges and their deformation behavior. Diagrams and an example suggest a process for design of this type of hinge.

**85-1143**  
**Nondestructive Testing of Joints.** 1972-  
August, 1984 (Citations from the Interna-  
tional Aerospace Abstracts Data Base)  
NTIS, Springfield, VA  
120 pp (Sept 1984), PB84-874049

**KEY WORDS:** Joints, Nondestructive tests,  
Bibliographies

This bibliography contains citations concerning techniques and technology for the nondestructive testing or evaluation of joints to detect flaws or defects that can affect properties and behavior. Attention is also given to evaluations of the strength of various types of joints.

## LINKAGES

**85-1144**  
**Generalized Equations of Motion for the  
Dynamic Analysis of Elastic Mechanism  
Systems**

D.A. Turcic, A. Midha  
Drexel Univ., Philadelphia, PA 19104  
J. Dynam. Syst., Meas. Control, Trans.  
ASME, 106 (4), pp 243-248 (Dec 1984), 5  
figs, 37 refs

**KEY WORDS:** Linkages, Elastic systems,  
Finite element technique

This paper develops the generalized equations of motion for elastic mechanism systems from finite element theory. The derivation and final form of the equations of motion provide the capability to model a general two- or three-dimensional complex elastic mechanism. Nonlinear rigid-body and elastic motion coupling terms can be included. Any finite element type can be utilized in the model.

**85-1145**  
**Dynamic Analysis of Elastic Mechanism  
Systems. Part I: Applications**

D.A. Turcic, A. Midha  
Drexel Univ., Philadelphia, PA 19104  
J. Dynam. Syst., Meas. Control, Trans.  
ASME, 106 (4), pp 249-254 (Dec 1984), 12  
figs, 8 refs

**KEY WORDS:** Linkages, Elastic systems,  
Four bar mechanisms, Equations of motion,  
Finite element technique

In this work an approach to the solution of the equations of motion is offered. Related considerations are also discussed. Applications to the analysis and solution method are presented. To demonstrate generality, an example is selected in which the geometrically complex follower link of a four-bar mechanism is modeled with quadrilateral finite elements.

**85-1146**  
**Dynamic Analysis of Elastic Mechanism  
Systems. Part II: Experimental Results**

D.A. Turcic, A. Midha, J.R. Bosnik  
Drexel Univ., Philadelphia, PA 19104  
J. Dynam. Syst., Meas. Control, Trans.  
ASME, 106 (4), pp 255-260 (Dec 1984), 16  
figs, 12 refs

**KEY WORDS:** Linkages, Four bar mechanisms, Experimental data, Elastic systems

This paper presents an experimental investigation of an elastic four-bar mechanism. The experimental four-bar mechanism coupler and follower strains help verify strains determined analytically. The strains com-

pare well in both amplitude and frequency content.

## SEALS

85-1147

### Identification of Dynamic Coefficients of Annular Turbulent Seals

R. Nordmann, H. Massmann

Univ. of Kaiserslautern, Fed. Rep. of Germany

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 295-311, 10 figs, 1 table, 9 refs

**KEY WORDS:** Seals, Parameter identification technique

This paper presents a procedure to determine dynamic coefficients of annular turbulent seals in turbopumps. Measurements were carried out at a test rig. A rigid rotating shaft is surrounded by an elastically supported housing, which is excited by impact forces. Relative radial motion between rotating parts and housing is measured by displacement pickups. Complex frequency response functions can be calculated from time signals. An analytical model dependent on seal parameters is fitted to measured data to obtain dynamic coefficients.

85-1148

### Analysis and Testing for Rotordynamic Coefficients of Turbulent Annular Seals with Different, Directionally Homogeneous Surface-Roughness Treatment for Rotor and Stator Elements

D.W. Childs, Chang-Ho Kim

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Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf.

Pub. No. 2338, pp 313-340, 13 figs, 2 tables, 12 refs

**KEY WORDS:** Seals, Damping coefficients, Surface roughness, Perturbation theory

An analytical-computational method is developed to calculate the transient pressure field and dynamic coefficients for high-pressure annular seal configurations. The solution procedure applies to constant-clearance or convergent-tapered geometries. They can have different surface-roughness treatments on the stator or rotor seal elements. It applies in particular to damper-seals that employ smooth rotors and deliberately-roughened stator elements to enhance rotor stability.

85-1149

### Analysis for Leakage and Rotordynamic Coefficients of Surface Roughened Tapered Annular Seals

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Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 341-349, 6 figs, 10 refs

**KEY WORDS:** Seals, Honeycomb structures, Surface roughness, Perturbation theory

This analysis develops an analytical-computational method to solve for the rotor dynamic coefficients of a honeycomb compressible-flow seal. An example case is used to demonstrate the effect of changing from a smooth to a rough stator while varying seal length, taper, preswirl, and clearance ratio.

85-1150

### Experimental Investigations of Lateral Forces Induced by Flow Through Model Labyrinth Glands

Y.M.M.S. Leong, R.D. Brown

Universiti Teknologi Malaysia, Jalan Gurney, Kuala Lumpur, Malaysia

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 187-210, 23 figs, 2 tables, 17 refs

**KEY WORDS:** Seals, Fluid-induced excitation

Data for circumferential pressure distributions, lateral forces, and stiffness coefficients are obtained experimentally and discussed. The force system can be represented as a negative spring and a tangential force orthogonal to eccentricity. The magnitude of these forces is dependent on eccentricity, entry swirl, rotor peripheral velocity, and seal size. Tests with a pressure equalization chamber at mid-gland resulted in significantly reduced forces and stiffness coefficients.

**85-1151**

**Theoretical Approach to Labyrinth Seal Forces - Cross-Coupled Stiffness of a Straight-Through Labyrinth Seal**

T. Kameoka, T. Abe, T. Fujikawa

Kobe Steel Ltd., Kobe, Japan

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 173-185, 10 figs, 4 refs

**KEY WORDS:** Seals, Fluid-induced excitation

Theoretical equations are developed to describe the motion of a jet flow and a core flow in a labyrinth seal. The pressure distribution within the labyrinth is calculated. Theoretical values for cross-coupled stiffness are obtained by integrating the pressure with various labyrinth geometries and operating conditions. These values are compared with experimental data. Theoretical and experimental results show satisfactory agreement.

**85-1152**

**Computer Modelling of the Functioning Modes of Non-Contacting Face-Seals**

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Trib. Intl., 17 (5), pp 269-276 (Oct 1984), 9 figs, 2 tables, 16 refs

**KEY WORDS:** Seals, Computer programs

This theoretical study examines the different functioning modes of mechanical face-seals. A computer program treats the floating-stator mounting arrangement in which the stator is assumed to have three degrees of freedom. Coning, waviness, and misalignment of both faces are accounted for. The problem of non-contacting face-seals is treated from the point of view of hydrostatic and hydrodynamic pressure. The Reynolds equation is solved with and without the narrow seal approximation.

**85-1153**

**Prediction of Force Coefficients for Labyrinth Seals**

O.W.K. Lee, M. Martinez-Sanchez, E. Czajkowski

Massachusetts Inst. of Technology, Cambridge, MA 02139

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 235-255, 14 figs, 3 tables, 23 refs

**KEY WORDS:** Seals, Fluid-induced excitation, Viscous damping

This paper reports development of a linear model for predicting labyrinth seal forces. Results are compared with available stiffness data. Relevance of fluid damping forces is discussed. Preliminary stages of a program to obtain data on these forces are reported.

**85-1154**

**Analysis of Dynamic Characteristics of Fluid Force Induced by Labyrinth Seal**

T. Iwatsubo, R. Kawai, N. Kagawa, T. Kakiuchi  
Kobe Univ., Rokkodai Kobe, Japan  
Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 211-234, 31 figs, 4 refs

**KEY WORDS:** Seals, Fluid-induced excitation

Flow patterns are experimentally investigated to develop a mathematical model of the labyrinth seal and to obtain the flow-induced force of the seal. The fluid force and its phase angle are obtained. Fluid force coefficients are derived. They are similar to the expression of oil-film coefficients. Vortices exist in the labyrinth chambers.

**85-1155**

**An Iwatsubo-Based Solution for Labyrinth Seals - Comparison with Experimental Results**

D.W. Childs, J.K. Scharrer  
Texas A & M Univ., College Station, TX 77843

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 257-279, 9 figs, 1 table, 14 refs

**KEY WORDS:** Seals, Fluid-induced excitation

Basic equations are derived for compressible flow in a labyrinth seal. The flow is assumed to be completely turbulent in the circumferential direction. Linearized zeroth and first-order perturbation equations are developed for small motion about a centered position. The Zeroth-order pressure distribution is found. The circumferential velocity distribution is determined. The first-order equations are solved. Integration of the resultant pressure distribution along and around the seal defines the reaction force. The corresponding dynamic coefficients are obtained.

## STRUCTURAL COMPONENTS

### CABLES

**85-1156**

**Optimal Cable Configurations for Passive Dynamic Control of Compliant Towers**

J.F. Wilson, G. Orgill  
Duke Univ., Durham, NC 27706  
J. Dynam. Syst., Meas. Control, Trans. ASME, 106 (4), pp 311-318 (Dec 1984), 8 figs, 3 tables, 22 refs

**KEY WORDS:** Cables, Towers, Cable-stayed structures, Offshore structures

Formulated here are a nonlinear dynamic model involving wind, wave, current, tower, and cable interactions and a cable optimization algorithm. The objective function, the rms tower rotation, is minimized. The function is subject to appropriate constraints involving compatible system geometries and loads. Bounds on platform level accelerations for human comfort are also considered. Tower motion is limited to a plane.

### BARS AND RODS

**85-1157**

**A Numerical Scheme for the Study of Poynting Effect in Wave Propagation Problems with Finite Boundaries**

S.V. Hanagud, N.S. Abhyankar  
Georgia Inst. of Technology, Atlanta, GA 30332  
Intl. J. Nonlinear Mech., 14 (6), pp 507-524 (1984), 17 figs, 26 refs

**KEY WORDS:** Rods, Wave propagation, Torsional excitation, Axial excitation

Effects of coupling of torsional and longitudinal waves has been studied for cylindrical rods of finite length. The resulting finite deformation elastodynamic problem has been solved by a finite difference

method that is a MacCormack two-step variant of Lax-Western second order accurate scheme. The accuracy of the numerical technique has been calibrated by comparing solutions with reported similarity solutions for semi-infinite rods. New results have been presented for finite rods and different loading conditions.

85-1158

**Impact of Work-Hardening Cylinders on a Rigid Boundary**

S.E. Jones, J.C. Foster, Jr., P.P. Gillis  
Univ. of Kentucky, Lexington, KY 40506  
Intl. J. Nonlinear Mech., 14 (6), pp 575-586  
(1984), 4 figs, 7 refs

**KEY WORDS:** Rods, Impact response, Wave propagation, Strain hardening

The problem of the impact response of a uniform cylinder of rigid-plastic work-hardening material is investigated. The elementary equations of motion are inverted through the Hodograph transformation. An exact solution for plane plastic wave propagation is given. This solution is expressed in terms of the motion of a rigid-plastic interface and the current velocity of rigid rod section. A simple example is discussed.

## BEAMS

85-1159

**Energy Conservation in the Transient Response of Nonlinear Beam Vibration Problems Subjected to Pulse Loading -- A Numerical Approach**

E.T. Moyer, Jr.  
The George Washington Univ., Washington, DC 20052  
Computers Struc., 12 (3), pp 339-344  
(1984), 5 figs, 2 tables, 10 refs

**KEY WORDS:** Cantilever beams, Pulse excitation, Nonlinear theories, Numerical methods

The nonlinear vibration response of a double cantilevered beam subjected to pulse

loading over a central sector is studied. The initial response is used to ascertain the energetics of the response. Total energy is used as a gauge of stability and accuracy of the solution. To obtain accurate and stable initial solutions an extremely high spatial and time resolution is required. This requirement was evident only by examining the energy of the system. It is proposed, therefore, to use total energy as a necessary stability and accuracy criterion for the nonlinear response of conservative systems. The results also demonstrate that, even for moderate nonlinearities, membrane forces significantly influence a system. It is also shown that although the fundamental response is contained in a first mode envelope, fluctuations caused by higher order modes must be resolved.

85-1160

**Optimization of Vibrating Beams Including the Effects of Coupled Bending and Torsional Modes**

A. Chattopadhyay  
Ph.D. Thesis, Georgia Inst. of Technology, 257 pp (1984), DA8424618

**KEY WORDS:** Beams, Flexural vibration, Torsional vibration, Optimization

The optimality criterion approach based on finite element techniques has been proposed for the optimum design of vibrating beams undergoing transverse as well as couple bending-torsion vibrations. The problem of minimizing the volume of the beam has also been addressed. A channel beam with simply supported boundary condition and a specified fundamental frequency are considered.

85-1161

**Dynamic Analysis of a Beam with an Intermediate Elastic Support**

P.L. Verniere de Irassar, G.M. Ficcadenti, P.A.A. Laura  
Inst. of Applied Mechanics, 8111 - Puerto Belgrano Naval Base, Argentina  
J. Sound Vib., 26 (3), pp 381-389 (Oct 8, 1984), 5 figs, 4 tables, 5 refs

**KEY WORDS:** Beams, Elastic supports, Approximation methods

An approximate solution is obtained for the case of a beam with ends elastically restrained against rotation and an intermediate elastic support. When dealing with forced vibration, a sinusoidally varying excitation is assumed.

**85-1162**

**The Effects of Large Vibration Amplitudes on the Fundamental Mode Shape of a Clamped-Clamped Uniform Beam**

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J. Sound Vib., 26 (3), pp 309-331 (Oct 8, 1984), 11 figs, 5 tables, 17 refs

**KEY WORDS:** Beams, Mode shapes

Nonlinear vibration of a clamped-clamped beam at large displacement amplitudes is examined. Theoretical and experimental studies have been carried out. Amplitude dependence of the fundamental mode shape and its derivatives is examined. The spatially-dependent harmonic distortion of the transverse displacement that occurs at large deflections is studied.

**85-1163**

**The Effects of Large Vibration Amplitudes on the Dynamic Strain Response of a Clamped-Clamped Beam with Consideration of Fatigue Life**

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J. Sound Vib., 26 (3), pp 281-308 (Oct 8, 1984), 18 figs, 3 tables, 24 refs

**KEY WORDS:** Beams, Fatigue life

Theoretical and experimental studies showed that harmonic distortion of the induced total strain, due to sinusoidal excitation at mid-span, is mainly due to the axial strain component. A limited set of fatigue experiments showed a decrease in

fatigue life due to nonlinear vibration compared to a cantilevered beam of the same material. A statistical approach to analysis of nonlinear vibration induced by random loading is examined theoretically and experimentally. Good correlation is achieved between predicted and measured fatigue lives.

**85-1164**

**Combined Experimental/Analytical Modeling Using Component Mode Synthesis**

D.R. Martinez, T.G. Carne, D.L. Gregory, A.K. Miller

Sandia National Labs., Albuquerque, NM

Rept. No. SAND-83-1889, 16 pp (Apr 1984), DE84013147

**KEY WORDS:** Beams, Natural frequencies, Mode shapes, Component mode synthesis

This study evaluates the accuracy of computed modal frequencies and mode shapes obtained from a combined experimental/analytical model for a simple beam structure. The structure was divided into two subsystems. One was tested to obtain free-free modes. A component mode synthesis (CMS) technique was used to directly couple experimental modal data base for one subsystem with a finite element model of the other subsystem to create an experimental/analytical model of the total structure. Sensitivity of CMS model predictions to errors in modal parameters and residual flexibilities is also examined.

## CYLINDERS

**85-1165**

**Propagating Waves and Edge Vibrations in Anisotropic Composite Cylinders**

K.H. Huang, S.B. Dong

Tianjin Univ., Tianjin, People's Rep. of China

J. Sound Vib., 26 (3), pp 363-379 (Oct 8, 1984), 2 figs, 1 table, 32 refs

**KEY WORDS:** Cylinders, Composite structures, Anisotropism

The entire dispersive spectra of a cylinder with cylindrical anisotropy are determined from three different algebraic eigenvalue problems deducible from the same finite element formulation. The eigenvalue problems are solved by efficient techniques based on subspace iteration. Examples of two four-layer angle-ply cylinders are presented to illustrate this comprehensive finite element analysis.

## FRAMES AND ARCHES

85-1166

**Parametrical Optimal Design of Funicular Arches Against Buckling and Vibration**  
J. Blachut

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Intl. J. Mech. Sci., **26** (5), pp 305-310 (1984), 5 figs, 11 refs

**KEY WORDS:** Arches, Design techniques, Vibration control

Optimal piecewise constant area distribution along a funicular transverse vibrating arch under external load is determined. Total volume is minimized.

85-1167

**Practical Examples of Pylon Stabilities**

H.G. Natke, W.J. Gerasch

Univ. of Hannover, Hannover, Germany

Engrg. Struc., **6** (4), pp 357-362 (Oct 1984), 12 figs, 9 refs

**KEY WORDS:** Struts, Wind-induced excitation

Two examples illustrate that damage can occur in pylons due to cross-wind loading. Measurements and theoretical tests showed that the structures were not stable. Cables were added to one pylon. Theoretical tests revealed that stability of the other was risk. Stability is assessed by changing two parameters (mass, diameter). Correla-

tion between relative amplitude and mass damping parameter should be noted for various profile forms.

## MEMBRANES, FILMS, AND WEBS

85-1168

**Control of the Dynamic Response of a Damped Membrane by Distributed Forces**

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J. Sound Vib., **26** (3), pp 391-406 (Oct 8, 1984), 15 figs, 13 refs

**KEY WORDS:** Rectangular membranes, Viscous damping

The damping out of oscillations of a rectangular membrane by distributed forces is solved analytically. The membrane may be subject to viscous damping and is clamped along the boundaries. The motion of the membrane is initiated by given initial displacement and velocity conditions. The basic control problem is to minimize deflection and velocity of displacements in a given period of time with the minimum possible expenditure of force. A quadratic vector performance index is chosen as the cost functional. The necessary conditions of optimality are obtained from a control theory approach. Numerical results are given for various problem parameters. Efficiency of the control mechanism is investigated.

## PANELS

85-1169

**Propagation of Bending Waves in a Periodically Stiffened Panel**

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Rept. No. FFA-TN-1984-12, FDRL-83-4, 122 pp (Feb 1984), N84-28119

**KEY WORDS:** Stiffened panels, Flexural waves, Wave propagation

The wave propagation characteristics of a semi-infinite, simply supported, periodically stiffened plate were analyzed using the propagation constant approach. The stiffened plate was also analyzed using an approximate description of stringer effects, the smear-out approximation. The cut-off frequency and rate of decay depend on the magnitude of the stiffening and the stiffener spacing. The approximate solution is valid for moderate magnitudes of stiffening if the stiffener spacing is smaller than half the wave length in the stiffened plate.

## PLATES

85-1170

### **Cyclic Behaviour of Plates Under In-Plane Loading**

Y. Fukumoto, H. Kusama

Nagoya Univ., Nagoya, Japan

Engrg. Struc., Z (1), pp 56-63 (Jan 1985), 7 figs, 13 refs

**KEY WORDS:** Rectangular plates, Steel, Cyclic loading

The theoretical cyclic behavior of simply supported steel rectangular plates under alternating in-plane uniaxial forces is described. A method of elastic and perfectly plastic large deflection-small strain analysis is explained. The strength of plates decreases with increasing number of cycles. The cyclic behavior of a flange element significantly affects deformation and energy dissipation of a thin-walled beam-column under cyclic bending. The axial force promotes considerable deterioration of beam-columns.

85-1171

### **Reflection Characteristics of Longitudinal Waves in a Semi-Infinite Cylindrical Rod Connected to an Elastic Infinite Plate**

H. Wada

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Intl. J. Mech. Sci., 26 (5), pp 311-323 (1984), 8 figs, 8 refs

**KEY WORDS:** Plates, Rods, Wave reflection, Mindlin theory

Both the Mindlin plate theory and the classical plate theory are employed. Shapes of the incident pulses for the numerical calculations are assumed to be square of a half sinusoid. Time histories of longitudinal strain at arbitrary points of the rod are presented. The differences between reflected waves obtained from Mindlin plate theory and those from classical plate theory are large when plate thickness is large or the plate is soft compared with the rod. Thus, the effects of plate rotary inertia and shear deformation are large in the case of thick or soft plate. Experimental results are closer to numerical results obtained from Mindlin plate theory than those obtained from classical plate theory.

85-1172

### **Multiple Mode Non-Linear Dynamic Analysis of Thick Orthotropic Elliptical Plates**

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J. Sound Vib., 26 (3), pp 353-361 (Oct 8, 1984), 5 figs, 5 tables, 19 refs

**KEY WORDS:** Plates, Flexural vibration, Berger theory

Berger-type dynamic equations expressed in terms of displacement components are used. Solutions are obtained by a multiple mode approach, Galerkin's method and the numerical Runge-Kutta procedure. Amplitude-period responses are discussed for three types of high modulus fibre-reinforced plates. Transverse shear deformation, modal interaction, orthotropic material properties, and plate parameters influence the nonlinear dynamic behavior of elliptical plates. Results are in close agreement with those available in the literature. This Berger-type approach simplifies analytical and computational efforts without producing any appreciable change in final results.

85-1173

**Normal Impact and Perforation of Thin Plates by Hemispherically-Tipped Projectiles — I. Analytical Considerations**

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Univ. of California, Berkeley, CA 94720

Int. J. Impact Engrg., 2 (3), pp 209-229 (1984), 15 figs, 24 refs

**KEY WORDS:** Plates, Projectile penetration

The study is directed toward determination of force and central plate deflection histories below and above the ballistic limit. The theory is based on a lumped-parameter system and is completely predictive below the ballistic limit. Calculated values were in excellent agreement below and in reasonable correspondence above the ballistic limit with data for soft aluminium targets. The current model appears to be the only one that forecasts the drop in peak force upon initiation of perforation and subsequent simultaneous motion of plug and target plate. These attributes and the ease of evaluating the model constitute the predominant justification for its employment.

## SHELLS

85-1174

**Theoretical and Experimental Results of Dynamic Behavior of Periodically Stiffened Cylindrical Shell**

L. Lecce, F. Marulo, A. Carbone, A. Paonessa

Inst. di Progetto Velivoli, Naples Univ., Italy

15 pp (1982) (Pres. at 10th Convegno Nazi. Dell'Assoc. Ital. Per l'Anal. Delle Sollecitazioni, Cosenza, Italy, pp 22-25 (Sept 1982), N84-27731 (In Italian)

**KEY WORDS:** Cylindrical shells, Stiffened shells, Aircraft noise

A computing procedure combining the transfer matrix method and wave transmission approach is developed. Depending on the frequency of excitation, one of two models is used: the skin-stringer model or

the cylinder-frame model. The measured transfer functions of fuselage structures are compared to theoretical predictions. Results are encouraging and show the need to improve experimental techniques.

85-1175

**Complex Eigenfrequencies of Rigid and Soft Spheroids**

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U.S. Naval Academy, Annapolis, MD 21402

J. Acoust. Soc. Amer., 77 (1), pp 6-9 (Jan 1985), 3 figs, 1 table, 24 refs

**KEY WORDS:** Natural frequencies, Spheres

The complex eigenfrequencies of impenetrable or penetrable target objects form a pattern that is characteristic in shape or composition for a given target. They manifest complex eigenfrequencies themselves as poles (resonances) in the amplitude of waves scattered from the object. Eigenfrequency patterns of acoustically rigid and soft spheroids in the complex frequency plane are obtained. Their displacements when eccentricity of spheroids is varied are studied. The eigenfrequencies were obtained numerically by subjecting spheroidal wavefunctions to Neumann or Dirichlet boundary conditions.

## PIPES AND TUBES

85-1176

**Studies on Stability of Two-Degree-of-Freedom Articulated Pipes Conveying Fluid (The Effect of a Spring Support and a Lumped Mass)**

Y. Sugiyama

Tottori Univ., Koyama-cho, Tottori-shi, Japan

Bull. JSME, 27 (234), pp 2658-2663 (Dec 1984), 12 figs, 12 refs

**KEY WORDS:** Pipes, Fluid-filled containers, Stability

The system is nonconservative. It becomes subject to flutter-type or divergence-type

instability depending on system parameters. The effect of an intermediate lateral spring support on stability is investigated. Results show that an additional spring support at the discharge end can be destabilizing. The combined effect of a spring support and a lumped mass is discussed. Neglecting internal damping can result in an erroneous flutter prediction, especially when a large lumped mass is attached to the free end. Experiments agreed reasonably well with theory.

85-1177

**Nonlinear Resonant Oscillations in Closed Tubes — An Application of the Averaging Method**

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J. Acoust. Soc. Amer., 77 (1), pp 61-66 (Jan 1985), 1 fig, 10 refs

**KEY WORDS:** Tubes, Resonant response, Averaging techniques

The averaging method is applied to a one-dimensional inhomogeneous, nonlinear acoustic wave equation with dissipative term. It is possible to give asymptotic solutions for any kind of external resonance excitation. The lowest-order solution consists of the superposition of two modulated counterpropagating waves. The amplitude of each is a wave solution of Burgers equation. The method extended to oscillating boundaries also leads to Burgers equations. Explicit stationary solutions are given for important external excitations, harmonic distributed forces, and harmonic oscillating boundaries. The application of several other computational methods to this problem leads to the same results.

85-1178

**Experiments on Vibration of Clusters of Cylinders in Axial Flow: Modal and Spectral Characteristics**

M.P. Paidoussis, J.O. Gagnon

McGill Univ., Montreal, Quebec, Canada

J. Sound Vib., 96 (3), pp 341-352 (Oct 8, 1984), 6 figs, 15 refs

**KEY WORDS:** Cylinders, Tube arrays, Fluid-induced excitation

The majority of tests were conducted with symmetric clusters of four flexible cylinders in a water tunnel. One or two of the cylinders were instrumented with embedded strain gauges to measure vibration in two mutually perpendicular planes of motion. Both modal and spectral characteristics agreed remarkably well with those predicted by a previously developed theory for the free-vibration characteristics of the system.

## BUILDING COMPONENTS

85-1179

**Computed Nonlinear Seismic Response of R/C Wall-Frame Structures**

M. Keshavarzian, W.C. Schnobrich

Univ. of Illinois at Urbana-Champaign, IL  
Rept. No. STRUCTURAL RESEARCH  
SER-515, UILU/ENG-84/2004, NSF/CEE-84/012, 230 pp (May 1984), PB84-224377

**KEY WORDS:** Walls, Reinforced concrete, Seismic response

This method is for nonlinear analysis of the response of a R/C coupled shear wall or wall-frame structure subjected to strong earthquake motion. The objective is to maintain simplicity in the method and produce reasonable reliability in the results. Computed responses of one cantilever column member, two coupled shear wall structures, and one wall-frame system under dynamic loads and static loads are compared with test results. Effects of moment-axial force interaction of wall members and pinching action and strength decay of coupling beams on overall computed responses of coupled shear wall structures are discussed.

85-1180

**On the Strength of Racks for Jack-up**

**Units. No. 1 Report: Fatigue Behavior of Large Scale, Torch-cut and Machined High Tensile Strength Steel Racks**

H. Honda, S. Kitamura, T. Yamada  
Mitsui Engrg. & Shipbuilding Co., Ltd., 6-4,  
5-chome, Tsukiji, Chuo-ku, Tokyo 104,  
Japan  
Bull. JSME, 27 (234), pp 2879-2888 (Dec 1984), 20 figs, 4 tables, 10 refs

**KEY WORDS:** Racks, Steel, Fatigue tests

This report presents the results of fatigue testing on torch cut and machined high tensile strength steel (HT80 steel) racks. Strain distributions along compressive and tensile fillets of the racks were obtained using the strain gage method. Results were compared with those obtained using a finite element technique. Relations between fatigue strength and strain amplitude at the most critically stressed point in the rack fillet were obtained. Crack propagation behavior in the rack fillets was observed using plastic replicas, a magnifying glass, crack gages, and the crack mark method. The results obtained are useful for fracture control of racks.

## **ELECTRIC COMPONENTS**

### **CONTROLS (SWITCHES, CIRCUIT BREAKERS)**

**85-1181**

**Guaranteed Tracking Behavior in the Sense of Input-Output Spheres for Systems with Uncertain Parameters**

S. Jayasuriya, M.J. Rabins, R.D. Barnard  
Michigan State Univ., East Lansing, MI 48824  
J.Dynam. Syst., Meas. Control, Trans. ASME, 106 (4), pp 273-279 (Dec 1984), 7 figs, 17 refs

**KEY WORDS:** Control equipment

Plant parameter uncertainties are assumed to be unknown-but-bounded. Design criteria are given for the synthesis of controllers

for such systems. Tracking specifications are formulated in terms of topological neighborhoods in normed function spaces. Feedback controllers are constructed by nonlinear state observers related to uncertain plants and utilizing the measured output. Results provide quantitative servo designs and precise error bounds for the specified tracking behavior. Two examples are a vibration isolation problem and a speed controller.

## **MOTORS**

**85-1182**

**Basic Equations for Computing the Electrical Part of Electromagnetic Vibrators**

V.S. Paškevičius, A.V. Šukelis, S.J. Kudarauskas  
Kaunas Polytechnic Institute, Kaunas, Lith. SSR  
Vibrotechnika, 2 (40), pp 121-124 (1983), 1 fig, 4 refs (In Russian)

**KEY WORDS:** Vibrators, Electromagnetic shakers

The article presents basic equations for computing the electrical part of electromagnetic vibrators. These equations are used to calculate design variants and carry out an optimization on a digital computer.

**85-1183**

**Frequency Characteristics of Electromechanical Vibrators**

V.S. Paškevičius, S.J. Kudarauskas, A.V. Šukelis  
Kaunas Polytechnic Institute, Kaunas, Lith. SSR  
Vibrotechnika, 2 (40), pp 125-132 (1983), 4 figs, 2 refs (In Russian)

**KEY WORDS:** Vibrators, Electromagnetic shakers

Dependence of factors on the frequency of anchor oscillations of electromechanical vibrators operating by electromagnetic

forces is discussed. Frequency characteristic equations for two variants of the equipment under discussion is discussed. The anchor is moving along or across the magnetic lines. The other extreme case is an electric power supply from a current or voltage source.

85-1184

**Dynamics of Ring-Type Vibromotor with Impact Interaction**

R. Barauskas, K. Ragulskis

Kaunas Polytechnic Inst., Kaunas, Lith. SSR  
Vibrotechnika, 1 (41), pp 61-68 (1983), 6 figs, 7 refs (In Russian)

**KEY WORDS:** Vibromotors, Impact excitation, Finite element technique

A ring-type vibromotor with impact interaction of input and output links is investigated by the finite element method. Tangential forces are determined with the help of dry friction hypothesis. A system of nonlinear differential equations of a finite element model of the vibromotor is presented. Results are given in the form of dependences and work characteristics of a vibromotor in a continuous-motion regime.

## DYNAMIC ENVIRONMENT

### ACOUSTIC EXCITATION

85-1185

**Noise Reduction in the Instrumentation Engineering (Geräuschminderung in der Gerätetechnik)**

W. Krause, I. Thümmler

Technische Universität Dresden, Sektion Elektronik-Technologie und Feingerätetechnik

Feingerätetechnik, 33 (10), pp 466-469 (1984), 6 figs, 4 tables, 15 refs (In German)

**KEY WORDS:** Noise reduction, Instrumentation

Higher operating speeds are connected with increased noise generation. Stricter requirements concerning noise reduction of functional components are necessary to the application of microelectronic units. This article establishes design results for accounting for these tendencies during product development.

85-1186

**A Trial of Probabilistic Evaluation for the Sound Insulation System Based on the Modified Method of Statistical Energy Analysis**

M. Ohta, S. Yamaguchi, N. Nakasako

Hiroshima Univ., Saijo-cho, Higashi-Hiroshima, 724 Japan

Acustica, 56 (4), pp 270-279 (Dec 1984), 9 figs, 2 tables, 19 refs

**KEY WORDS:** Statistical energy analysis, Acoustical insulation, Noise control

A new trial based on two probabilistic evaluation methods of a sound insulation system is proposed. It has the form of a probability distribution of sound level. A general stationary random noise with arbitrary probability and frequency characteristics is insulated by a wall. A modified method of statistical energy analysis is used. Experimental results are in good agreement with theoretically values.

85-1187

**A Contribution About Description of Excitation of Sound in Solids Caused by Cranks (Ein Beitrag zur Beschreibung der Körperschallanregung durch Kurvengetriebe)**

J. Wildoer, K. Knothe

Technische Universität Dresden, Sektion Arbeitswissenschaften, German Dem. Rep. Maschinenbautechnik, 33 (9), pp 412-414 (1984), 4 figs, 3 refs (In German)

**KEY WORDS:** Noise generation, Machinery, Noise control

Structure-borne noise is described theoretically by means of motion cycles. A computer-aided determination of curves for excitation spectra is presented. The effect of the disturbance accelerations on the excitation of structure-born noise is discussed.

**85-1188**

**Effect of Turbulent Boundary Layer Flow on Measurement of Acoustic Pressure and Intensity**

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State College, PA 16804

Noise Control Engrg. J., 23 (2), pp 52-59  
(Sept/Oct 1984), 7 figs, 18 refs

**KEY WORDS:** Acoustics measurement, Fluid-induced excitation, Turbulence

A simple analysis is given whereby the flow noise response of a pressure sensor in a turbulent boundary layer flow can be estimated. If the purpose of the sensor is to measure sound emitted from source outside the turbulent boundary layer, a bias for the measurements can be calculated. A bias formula for intensity measurements with the two-sensor technique under a turbulent boundary layer is derived. A very low Mach number flow is assumed. This bias is small when sensor separations are large compared to correlation lengths of turbulent pressure fluctuations.

**85-1189**

**Saturation of a Nonlinear Cylindrical Sound Wave Generated by a Sinusoidal Source**

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Royal Inst. of Technology, S-100 44 Stockholm, Sweden

J. Acoust. Soc. Amer., 77 (1), pp 54-60  
(Jan 1985), 1 table, 12 refs

**KEY WORDS:** Sound waves, Wave propagation, Periodic excitation

A generalized Burgers' equation with two dimensionless parameters is used. The amplitude of the wave at a large distance

from the source is determined for two parameters in a region. Amplitude is given by a single number independent of the parameters. A series expansion of the solution of the generalized Burgers' equation is sought. The series converges far from the source and in the Taylor shock region closer to the source. Despite the slow convergence of the series in the latter region it is possible to find the desired amplitude. An asymptotic expression for the terms in the series and some numerical work is required.

**85-1190**

**Theory and Applications of a High-Resolution Synthetic Acoustic Antenna for Industrial Noise Measurements**

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2600 GA Delft, The Netherlands

Noise Control Engrg. J., 23 (2), pp 60-68  
(Sept/Oct 1984), 12 figs, 6 refs

**KEY WORDS:** Noise measurement, Industrial facilities

A high resolution synthetic acoustic antenna (SYNTACAN) has been developed to measure industrial noise. The antenna consists of a sparse line-array of 32 microphones and an on-line data acquisition and analysis system. It covers the frequency range from 90 to 1400 Hz and has a resolving power of 1.5 degrees. It is shown theoretically that the influence of atmospheric disturbances can be eliminated under practical conditions. SYNTACAN has proven a valuable tool for industry and government for the evaluation of excessive noise levels.

**85-1191**

**Sound Scattering by a Group of Oscillatory Cylinders**

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Components Technology Div., Argonne National Lab., 9700 S. Cass Ave., Argonne, IL

J. Acoust. Soc. Amer., 77 (1), pp 15-28  
(Jan 1985), 17 figs, 2 tables, 20 refs

**KEY WORDS:** Acoustic scattering

An analytical study was made of multiple scattering of a plane sound wave by a group of circular, rigid cylinders oscillating in an ideal fluid. One objective was to investigate multiple scattering due to the movement of many scatterers in the passage of sound waves. Effects of multiple scattering and oscillations of scatterers on scattering functions were determined. The fluid medium was assumed inviscid and compressible. Solid cylinders were assumed to move freely under the action of sound waves. The acoustical radiation field caused by the translatory oscillations of the cylinders was taken into account.

**85-1192**

**Spectral Analysis of Echoes for Backscattering Coefficient Measurement**

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J. Acoust. Soc. Amer., *77* (1), pp 38-47 (Jan 1985), 8 figs, 1 table, 19 refs

**KEY WORDS:** Spectral analysis, Acoustic scattering

This paper describes spectral analyses of echoes scattered by a random medium and a plane reflector using mathematical expressions of echoes. The spectrum is expressed in terms of a backscattering coefficient of the random medium and a velocity potential of an ultrasonic transducer. The expressions hold for any sound field if a correlation length of the random medium is much smaller than a beamwidth and a radius of the transducer. A ratio of two spectrums allows formulation of an expression for the backscattering coefficient of the random medium. It works in a farfield of a flat circular transducer and at a focal plane of a concave one. The formula contains cases that have been proposed as extremes. The backscattering coefficients of sponges were measured with several transducers. The formula gives coefficients regardless of transducer geometry.

**85-1193**

**A Simple, Complete Numerical Solution to the Problem of Diffraction of SH Waves by an Irregular Surface**

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Massachusetts Inst. of Tech., Cambridge, MA 02139

J. Acoust. Soc. Amer., *77* (1), pp 1-5 (Jan 1985), 6 figs, 24 refs

**KEY WORDS:** Elastic waves, Shear waves, Wave diffraction

The technique is applicable to boundaries of arbitrary shape and steepness as well as to periodically corrugated surfaces. It is valid at all frequencies. Surface forces that cancel the incident stress along the surface are determined. The method relies on introducing a periodicity in surface shape and discretizing the boundary at regular spacing. Surface sources that radiate the scattered wave field are obtained by iteration. Examples of calculations and comparisons with other methods are presented.

**85-1194**

**A Time-Domain Energy Theorem for Scattering of Plane Acoustic Waves in Fluids**

A.T. de Hoop

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J. Acoust. Soc. Amer., *77* (1), pp 11-14 (Jan 1985), 1 fig, 6 refs

**KEY WORDS:** Elastic waves, Sound waves, Wave scattering, Time domain method

The theorem for the scattering of plane acoustic waves in fluids by an obstacle is the counterpart in the time domain of the optical theorem or extinction cross section theorem in the frequency domain. No assumptions as to the acoustic behavior of the obstacle need to be made. Three kinds of time behavior are distinguished: transient, periodic, and perpetuating, but with finite mean power flow density. Total energy or time-averaged power absorbed and scattered by the obstacle is related to a time interaction integral of the incident planewave and a spherical-wave amplitude of the scattered wave in the farfield region.

## SHOCK EXCITATION

85-1195

### Delamination Growth Analysis in Quasi-Isotropic Laminates Under Loads Simulating Low-Velocity Impact

K.N. Shivakumar, W. Elber

NASA Langley Res. Ctr., Hampton, VA

Rept. No. NASA-TM-85819, 27 pp (June 1984), N84-27833

**KEY WORDS:** Layered materials, Impact response, Finite element technique

A geometrically nonlinear finite-element analysis was developed to calculate the strain energy released by delamination plates during impact loading. Only the first mode of deformation, which is equivalent to static deflection, was treated. Both impact loading and delamination in the plate were assumed to be axisymmetric. Energy release rates for various delamination sizes and locations and for various plate configurations and materials were compared.

85-1196

### Propagation of a Slant Crack Under Impact Studied by Caustics

P.S. Theocaris, A.A. Serafetinides

The National Technical Univ. of Athens, 5, Heroes of Polytechnion Ave., GR-157 73 Athens, Greece

Intl. J. Impact Engrg., 2 (3), pp 251-261 (1984), 7 figs, 18 refs

**KEY WORDS:** Crack propagation, Impact response

An air gun was used to produce the load pulse. The steady crack velocity increased linearly with the angle of crack inclination. Velocity reached a maximum value when initial crack was normal to load direction. The crack started to propagate in the presence of both  $K_I$  and  $K_{II}$  stress intensity factors. The  $K_{II}$  factor has a maximum value of one-tenth of the  $K_I$  factor and an oscillatory character. This becomes zero in the first third of the crack-path. For the same values of  $K_I$  and

$K_{II}$ , the crack propagates in some cases with different velocities, apparently depending on the initial crack inclination.

85-1197

### Effects of Suction on Shock/Boundary-Layer Interaction and Shock-Induced Separation

P. Krogmann, E. Stanewsky, P. Thiede

DFVLR, Inst. for Experimental Fluid Mechanics, Gottingen, Fed. Rep. of Germany

J. Aircraft, 22 (1), pp 37-42 (Jan 1985), 17 figs, 8 refs

**KEY WORDS:** Shock wave-boundary layer interaction

An experimental investigation of the effects of local boundary-layer suction on shock/boundary-layer interaction and shock-induced separation was conducted. Three different methods of suction were applied in the shock region. Their effectiveness in comparison to the basic closed-surface airfoil was evaluated. It was shown that local boundary-layer suction in the shock region delays development of shock-induced separation and improves overall aerodynamic characteristics. Two of the configurations showed even without suction a favorable passive effect on shock/boundary-layer interaction and overall flow development. They offer promising means for extending the range of applicability of transonic airfoils.

85-1198

### Investigation of Scattering and Diffraction of Plane Seismic Waves Through Two Dimensional Inhomogeneities

N. Moeen-Vaziri

Ph.D. Thesis, Univ. of Southern California (1984)

**KEY WORDS:** Seismic waves, Wave scattering, Wave diffraction, Least squares method

A least-squares technique was employed. Two numerical methods were proposed. Results are obtained using the series expansion in terms of Bessel and Hankel

functions. This approximate method is applied to idealized cross sections along profiles of Los Angeles basin. The study also includes an analysis of transient motions using the transfer functions obtained from harmonic analysis.

**85-1199**

**Probabilistic Approach to the Wave Propagation in Structured Solids**

D.R. Axelrad, M. Ostojca-Starzewski  
McGill Univ., Montreal, Canada

Intl. J. Engrg. Sci., 22 (8-10), pp 1123-1133 (1984), 3 figs, 12 refs

**KEY WORDS:** Wave propagation, Pulse excitation

The concept of two distinct time scales in the wave propagation process is introduced. Representation is given in terms of semi-group evolution operators. The formulation is carried out for one-dimensional and three-dimensional models of the solid. It has a cubic microstructure and random physical properties.

**85-1200**

**The Computer Simulation of an Explosive Test Rig to Determine the Spall Strength of Metals**

J.M. Yellup

Materials Res. Labs., Defence Science & Technology Organization, P.O. Box 50, Ascot Vale, Victoria, Australia 3032

Intl. J. Impact Engrg., 2 (2), pp 151-167 (1984), 14 figs, 1 table, 17 refs

**KEY WORDS:** Simulation, Explosion effects, Metals, Spalling

Spall fracture is produced by a tensile wave after reflection of a compressive shock wave at a free surface. A computer simulation using the EPIC-2 code was made and compared to published values. Good agreement was obtained by careful choice of input parameters. The computer simulation allowed extrapolation of pressure values to longer bar lengths to obtain the limit of incipient spall fracture. Informa-

tion was obtained on shock pulse shape and pressure distribution across the bar. The spall strength of a 6061-T6 aluminium alloy was 1400 MPa, in good agreement with published values for a similar pulse duration.

**VIBRATION EXCITATION**

**85-1201**

**Six Degree of Freedom Vibration Stress Screening**

G.K. Hobbs, R. Mercado

Hobbs Engrg. Corp., Lake Forest, CA

J. Environ. Sci., 27 (6), pp 46-53 (Nov/Dec 1984), 37 figs, 3 refs

**KEY WORDS:** Shakers, Vibrators (machinery)

To understand the behavior of the quasi-random multiaxis shaker, investigations of motions in time and frequency domains were undertaken. Included were the relationships of three linear axes and three rotational axes. The six axes of motion can be considered independent in terms of specimen response to input motions.

**85-1202**

**Forced Vibration of a Base-Excited Single-Degree-of-Freedom System with Coulomb Friction**

E. Marui, S. Kato

Gifu Univ., 1-1, Yanagido, Gifu-shi 501-11, Japan

J. Dynam. Syst., Meas. Control, Trans. ASME, 106 (4), pp 280-285 (Dec 1984), 15 figs, 5 refs

**KEY WORDS:** Single degree of freedom systems, Coulomb friction, Base excitation

An analytical technique is presented to describe the behavior of a linear forced vibratory system under the influence of a Coulomb friction force. Behavior of the system is determined by three non-dimensional parameters of non-dimensional fric-

tion force, frequency ratio, and damping ratio. The vibratory system undergoes a periodic vibration with stopping periods when the mass cannot move. These stopping periods increase at lower exciting frequencies and to Coulomb friction. The relation between the motion occurring and the three parameters can be obtained theoretically and verified experimentally.

**85-1203**

**Non-Gaussian Closure Techniques for Stationary Random Vibration**

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Intl. J. Nonlin. Mech., 20 (1), pp 1-8 (1985), 3 figs, 8 refs

**KEY WORDS:** Random vibrations

A classical method of statistical linearization can be applied to a nonlinear oscillator excited by stationary wide-band random excitation. It can be considered a procedure in which unknown parameters in a Gaussian distribution are evaluated by moment identities. A systematic extension of this procedure is the method of non-Gaussian closure. An increasing number of moment identities are used to evaluate additional parameters in a family of non-Gaussian response distributions. The method is described and illustrated. Attention is given to the representations of non-Gaussian distributions and to techniques for generating independent moment identities. Some shortcomings of the method are pointed out.

**85-1204**

**Interaction of Fundamental Parametric Resonances with Subharmonic Resonances of Order One-Half**

A.H. Nayfeh

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J. Sound Vib., 26 (3), pp 333-340 (Oct 8, 1984), 3 figs, 10 refs

**KEY WORDS:** Parametric resonance, Subharmonic oscillations

Interaction of fundamental parametric resonances with subharmonic resonances of order one-half in a single-degree-of-freedom system with quadratic and cubic nonlinearities is investigated. The method of multiple scales is used to derive two first-order ordinary differential equations. They describe modulation of the amplitude and the phase of the response with nonlinearity and both resonances. These equations are used to determine the steady state solutions and their stability. Conditions are derived for quenching or enhancing a parametric resonance by adding a subharmonic resonance of order one-half. The degree of quenching or enhancement depends on the relative amplitudes and phases of the excitations. The analytical results are verified by numerically integrating the original governing differential equation.

**85-1205**

**Reduction of Effectiveness of Means for Suppressing Wind-Induced Oscillation**

M.M. Zdravkovich

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Engrg. Struc., 6 (4), pp 344-349 (Oct 1984), 9 figs, 27 refs

**KEY WORDS:** Wind-induced excitation

The aim of this paper is to describe the mechanism of eddy shedding, to explain the means for suppression of eddy shedding, and to indicate causes that render them ineffective. Important for practical application is the post-critical regime. Some cases are given when a significant reduction of effectiveness is expected.

**85-1206**

**Stability of Linear Non-Conservative Systems**

O. Danek

Inst. of Thermomechanics, Czechoslovak Academy of Sciences, Prague, Czechoslovakia

Strojnícky Časopis, 35 (5), pp 559-562 (1984), 2 refs (In Czech)

**KEY WORDS:** Stability, Nonconservative forces

A stability condition given by a sum of instantaneous powers within a single period of a harmonic motion is derived. It represents a generalization of formulas already derived.

**85-1207**

**Study of the Variations of Main Links of Magnetic Tape Constructions**

V. Strijhak, Bui Ngok Hoi

L'vovskii polytekhnikeskii institut, Lvov, Ukr.SSR

Vibrotechnika, 2 (40), pp 23-30 (1983), 6 figs, 3 refs (In Russian)

**KEY WORDS:** Magnetic tapes

This paper describes variations of a main link of tape-pulling mechanisms under variable moments of load resistance in the process of recording (playing).

**85-1208**

**Effect of System Parameters on Non-Linear Resonances in Parametrically Excited System Subjected to Self-Excitation**

S. Yano

Fukui Univ., Fukui, Japan

Strojnicky Casopis, 35 (5), pp 545-558 (1984), 9 figs, 1 table, 5 refs

**KEY WORDS:** Parametric excitation, Self-excited vibrations, Van der Pol method

A system with both linear and nonlinear parametric excitation subjected to self-excitation of Van der Pol type is compared with a system having only nonlinear parametric excitation. The effects of system parameters on the occurrence of resonances of order  $1/2$ , 1, and 2 are investigated.

## MECHANICAL PROPERTIES

### DAMPING

**85-1209**

**Two-Component Active Damping of Vibration in Rotor Machines**

K. Ragulskis, B. Stulpinas, A. Šukelis

Kaunas Polytechnic Institute, Kaunas, Lith. SSR

Vibrotechnika, 2 (40), pp 133-142 (1983), 8 figs, 8 refs, (In Russian)

**KEY WORDS:** Supports, Active damping, Rotors, Electromagnetic properties

Theoretical and experimental investigations were carried out on a two-component electromagnetic support. An active vibration damping system in a rotor machine was constructed on the supports. The results of studies of the system are presented.

**85-1210**

**Effects of Fluid Inertia and Turbulence on Force Coefficients for Squeeze Film Dampers**

L. San Andres, J.M. Vance

Texas A & M Univ., College Station, TX 77843

Rotordynamic Instability Problems in High-Performance Turbomachinery, Proc. of Workshop, Texas A & M Univ., College Station, TX, May 28-30, 1984, NASA Conf. Pub. No. 2338, pp 365-390, 9 figs, 2 tables, 13 refs

**KEY WORDS:** Squeeze-film dampers, Fluid-induced excitation, Turbulence

Both convective and temporal terms are included in the analysis of inertia effects. The analysis of turbulence is based on friction coefficients currently found in the literature for Poiseuille flow. The effect of fluid inertia on the magnitude of the radial direct inertia coefficient is completely reversed at large eccentricity ratios due to the inclusion of convective inertia terms in the analysis. Turbulence produced

a large effect on the direct damping coefficient at high eccentricity ratios. For the long or sealed squeeze film damper at high eccentricity ratios, the damping prediction with turbulence included is an order of magnitude higher than the laminar solution.

**85-1211**

**Squeeze-Film Dampers for Turbomachinery Stabilization**

L.J. McLean, E.J. Hahn  
Univ. of New South Wales, Kensington,  
N.S.W., 2033, Australia  
Rotordynamic Instability Problems in High-  
Performance Turbomachinery, Proc. of  
Workshop, Texas A & M Univ., College  
Station, TX, May 28-30, 1984, NASA Conf.  
Pub. No. 2338, pp 391-405, 5 figs, 6 refs

**KEY WORDS:** Squeeze-film dampers, Turbomachinery

A technique for investigating stability and damping in centrally preloaded radially symmetric multi-mass flexible rotor bearing systems is presented. Eigenvalues of the linearized perturbation equations or zero frequency stability maps are needed. The technique is illustrated for a simple symmetric four-degree-of-freedom flexible rotor with an unpressurized damper. Although zero frequency stability maps are probably a simple way to delineate solution possibilities, they do not provide full stability information. And for low bearing parameters the introduction of an unpressurized squeeze-film damper can promote instability in an otherwise stable system.

**85-1212**

**Damping Capacity of a Sealed Squeeze Film Bearing**

M.M. Dede, M. Dogan, R. Holmes  
Univ. of Southampton, Southampton, UK  
Rotordynamic Instability Problems in High-  
Performance Turbomachinery, Proc. of  
Workshop, Texas A & M Univ., College  
Station, TX, May 28-30, 1984, NASA Conf.  
Pub. No. 2338, pp 407-427, 9 figs, 6 refs

**KEY WORDS:** Damping, Squeeze-film bearings

Attention is given to empirically modeling the hydrodynamics of a tightly-sealed squeeze-film bearing. The object is to assess damping performance.

**85-1213**

**Experimental Measurements of Material Damping in Free Fall with Tunable Excitation**

E.F. Crawley, D.G. Mohr  
Massachusetts Inst. of Technology, Cambridge, MA  
AIAA J., 23 (1), pp 125-131 (Jan 1985), 11 figs, 2 tables, 13 refs

**KEY WORDS:** Material damping, Measurement techniques, Spacecraft

An initially simply supported test specimen was simultaneously excited and lofted into free fall with a spring-mass launcher. Damping information was obtained from the transient response of the specimens while in free fall in vacuum. A dynamic model of the launch process indicates the frequency range and initial specimen stress amplitude over which tests can be performed. Damping values in aluminum were close to theoretical values and independent of stress levels below 130 MPa (18.7 ksi).

**85-1214**

**Minimization of the Variance in Oil-Film Damping Coefficient Estimates**

M.N. Sahinkaya, O.S. Turkay, C.R. Burrows  
Univ. of Strathclyde, Glasgow, Scotland  
J. Dynam. Syst., Meas. Control, Trans. ASME, 106 (4), pp 342-348 (Dec 1984), 8 figs, 2 tables, 12 refs

**KEY WORDS:** Damping coefficients, Oil-film bearings, Frequency domain method

The frequency-domain algorithm to estimate oil-film bearing coefficients uses a least squares estimator and produces variances and confidence bounds for estimates. Variances can be minimized by correct design of the experimental procedure and by a data analysis package. Coefficient estimates are obtained by applying a mul-

ti-frequency test signal, measuring the applied force and corresponding journal displacements along orthogonal axes, and implementing the estimator. The paper discusses the use of D-optimality to select the measurement axes to improve the quality of estimates. Experimental results obtained from a squeeze-film bearing rig are presented.

**85-1215**

**Elastomer-Metal Damper Elements for Rail-Vehicle Construction (Elastomer-Metall-Dämpfungselemente für den Schienenfahrzeugbau)**

K.G. Pommereit

Inhaber der Firmen Pommereit Engrg. und Pollereit GmbH, Altdorf/Nürnberg  
Feinwerktech. u. Messtech., 22 (7), pp ZM111-ZM114 (Oct/Nov 1984), 8 figs, 3 refs (In German)

**KEY WORDS:** Dampers, Elastomers, Metals, Railroad trains

Elastomer-metal spring and damping elements are used to improve running behavior and quietness of rail-mounted vehicles. Both the shaping process and the choice of materials have an effect on elastic and damping characteristics. Limits on the shaping are dictated by a need to attain the least possible installed size. An elastomer-metal damper element for an eight-axled, low-platform carriage is used as an example.

## FATIGUE

**85-1216**

**Fatigue Induced Cracking in Aluminum LN<sub>2</sub> Shroud of 39-Foot Vacuum Chamber**

A.A. Edwards

Ford Aerospace and Communications Corp., Western Dev. Lab. Div., Palo Alto, CA  
J. Environ. Sci., 22 (6), pp 33-34, 39-42 (Nov/Dec 1984), 11 figs

**KEY WORDS:** Fatigue life, Aluminum, Test facilities, Spacecraft

Fourteen years after completion of Ford's 39-ft (12 m) space simulation chamber, leaks began to appear in the LN<sub>2</sub> shroud. Although the shroud had been tight since its acceptance, cracks appeared in 1983 in some field welds of one inch tubes connecting the LN<sub>2</sub> panels. Resulting leaks were large enough to prevent pump down to high vacuum and could be heard easily when the chamber was at ambient conditions. New cracks appeared during each thermal cycle making it impossible to utilize the chamber for thermal vacuum testing.

**85-1217**

**Study on Crack Growth Behavior in Impact Fatigue - Part III, Fatigue Crack Growth Behaviors of 2017-T3 Aluminum Alloy**

H. Nakayama, Y. Kanayama, M. Shikida, T. Tanaka

Osaka Industrial Univ., Nakagaito, Daito-city, Osaka, Japan  
Bull. JSME, 22 (234), pp 2599-2604 (Dec 1984), 13 figs, 11 refs

**KEY WORDS:** Fatigue life, Crack propagation, Aluminum

Results are compared with those obtained under nonimpact fatigue with the same stress ratios. In impact fatigue da/dN is higher than that in nonimpact fatigue under both stress ratio conditions. The discrepancy in da/dN due to the difference in stress does not disappear in an evaluation based on the effective stress intensity factor range. Peculiarities of impact fatigue crack growth behavior obtained in this study resemble those for low carbon steel.

**85-1218**

**Probabilistic Fatigue -- Theory and Experimentation**

J.W. Provan

McGill Univ., Montreal, Quebec, Canada H3A 2K6  
Intl. J. Engrg. Sci., 22 (8-10), pp 1065-1073 (1984), 6 figs, 16 refs

**KEY WORDS:** Fatigue life, Metals, Probability theory

This paper reports on research to make judgements as to the likelihood of fatigue failure of polycrystalline metals. Theoretical and experimental investigations of the stochastic nature of actual material degradation processes are used. Results of theoretical and experimental investigations are used to indicate the number of cycles involved in initiating a fatigue crack. Approximately 90% of the number of cycles to failure are involved in initiating a crack. The remainder are associated with propagation. Results of an acoustic emission test program are described.

**85-1219**

**Maximax Response and Fatigue Damage Spectra - Part II: Definition and Use for Vibration and Shock Test Specifications Establishment**

C. Lalanne

J. Environ. Sci., 27 (5), pp 40-44 (Sept/Oct 1984), 9 figs, 12 refs

**KEY WORDS:** Fatigue life, Maximax response, Response spectra

Criteria of extreme-response spectra and of fatigue-damage spectra are defined. Levels of severity of several vibrations or shocks are compared. Specifications of the same severity as a complex vibratory environment made up of vibrations of various origins are elaborated.

**85-1220**

**Apparatus to Study Fatigue Process Using High Amplitude Internal Friction Technique**

S. Okuda, H. Mizubayashi, Y. Tago

Inst. of Materials Science, Univ. of Tsukuba, Sakuramura, Ibaraki 305, Japan

J. Phys. E: Sci. Instrum., 17 (12), pp 1117-1118 (Dec 1984), 4 figs, 7 refs

**KEY WORDS:** Fatigue life, Measurement techniques, Internal friction

An automatic apparatus to study a fatigue process has been developed. Changes in internal friction and elastic modulus of specimens can be measured in situ during the progress of fatigue.

**85-1221**

**A Simplified Method for Assessing Wind-Induced Fatigue Damage**

K. Patel, P. Freathy

Atkins Res. and Dev., Woodcote Grove, Ashley Rd., Epsom, Surrey KT18 5BW, UK  
Engrg. Struc., 6 (4), 268-273 (Oct 1984), 6 figs, 3 refs

**KEY WORDS:** Fatigue life, Wind-induced excitation

Normalizing damage in a certain way results in a value completely independent of wind spectrum and structure. It is necessary only to compute denormalizing factors readily found from wind data and structural analyses. The proposed method is believed to be suitable for a first assessment of fatigue performance. Its simplicity and presentation in calculation sheet format should result in ease of use by design engineers.

**85-1222**

**A Stochastic Theory of Fatigue Crack Propagation**

Y.K. Lin, J.N. Yang

Florida Atlantic Univ., Boca Raton, FL

AIAA J., 23 (1), pp 117-124 (Jan 1985), 11 figs, 27 refs

**KEY WORDS:** Fatigue life, Crack propagation, Stochastic processes

This theory to analyze the propagation of fatigue crack is based on the concepts of fracture mechanics and random processes. Time-dependent crack size is approximated by a Markov process. Analytical expressions are obtained for the probability distribution of crack size at any given time. Probability distribution of the random time at which a given crack size is reached is conditional on knowledge of initial crack size. Examples illustrate application of the theory. Results are compared with available experimental data.

**85-1223**

**Analysis of Dynamic Mixed-Mode Crack Tip Stress Patterns**

M. Ramulu, D.B. Barker, A.S. Kobayashi  
Washington Univ., Seattle, WA  
Rept. No. UWA/DME/TR-84/49, 36 pp (May  
1984), AD-A143 329

**KEY WORDS:** Crack propagation

The mixed-mode, elasto-dynamic state of stresses in the neighborhood of a rapidly running crack tip is used to develop a relation between the isochromatic fringe order and its position parameters. Maximum shear stress is expressed in terms of stress intensity factors and other higher order terms involving the mixed-mode loading for a crack propagating at constant velocity. A graphics package was developed for mapping isochromatics in the vicinity of a running crack tip. It is used to illustrate typical mixed-mode isochromatics.

**85-1224**  
**Three-Dimensional Measurements of Fatigue Crack Closure**

S.K. Ray, A.F. Grandt, Jr.  
Purdue Univ., Lafayette, IN  
Rept. No. NASA-CR-173679, 126 pp (July  
1984), N84-28110

**KEY WORDS:** Fatigue life, Crack propagation

Fatigue crack growth and retardation experiments conducted in polycarbonate test specimen are described. The transparent test material allows optical interferometry measurements of the fatigue crack opening (and closing) profiles. Crack surface displacements are obtained from specimen thickness. Three-dimensional aspects of fatigue crack closure are discussed.

**85-1225**  
**Stage II Fatigue Crack Growth**

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Inst. of Low Temperature Physics and  
Engrg., Ukr.SSR Academy of Sciences, 47  
Lenin Ave., Kharkov 310164, USSR  
Intl. J. Fatigue, 6 (4), pp 229-242 (Oct  
1984), 15 figs, 100 refs

**KEY WORDS:** Fatigue life, Crack propagation

The linear part of the fatigue crack growth diagram is divided into Stages IIa and IIb by a point O. Coordinates  $K^*$  and A are dependent on physical and structural characteristics of the material.  $K_{eff}$  remains constant in Stage IIa as the microcrack advances in increments corresponding to the dislocation cell structure size.  $K_{op}$  remains constant during Stage IIb. The microcrack opens during each cycle and advances irrespective of the substructure but in accordance with an increasing value of  $K_{eff}$ . Effects of temperature and vacuum on  $K^*$  are considered. A values are independent of the above effects.

**85-1226**  
**A Kink in the Fatigue Crack Growth Curve**

V.M. Radhakrishnan  
Dept. of Metallurgy at the Indian Inst. of  
Technology, Madras-600 036, India  
Intl. J. Fatigue, 6 (4), pp 217-220 (Oct  
1984), 6 figs, 12 refs

**KEY WORDS:** Fatigue life, Crack propagation, Steel

The effect of grain size on the near threshold stress intensity factor in a low-carbon steel has been studied. In Stage I crack propagation depends on the microstructure of the material. In Stage II the growth rate curves for different grain sizes appear to merge. A kink or dip in the propagation rate where Stages I and II meet represents a retardation in crack growth. Analysis of published data shows that such a kink often occurs. It is proposed that this temporary retardation in crack growth is due to resistance offered by the grain boundary to the plastic zone when it tries to cross the first grain and move on to adjacent grains.

**85-1227**  
**Low Cycle Fatigue Life Enhancement of 316 L Stainless Steel by Nitrogen Alloying**

J.B. Vogt, S. Degallaix, J. Foct

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Intl. J. Fatigue, 6 (4), pp 211-215 (Oct 1984), 8 figs, 10 refs

**KEY WORDS:** Fatigue life, Steel

Tests at room temperature on 316 L stainless steels with different nitrogen contents show that nitrogen improves low cycle fatigue resistance. Saturation occurs when nitrogen content is above 0.12 weight percent. Microstructural aspects are also studied. Deformation is more difficult and more planar when nitrogen is present. Nitrogen delays cell formation. A relation derived from the Manson-Coffin formula describes the low cycle fatigue behavior of these steels. The relation accounts for plastic strain range and nitrogen content.

**85-1228**

**Fatigue Life Prediction of a Structural Steel Under Service Loading**

N.A. Fleck, R.A. Smith  
Cambridge Univ. Engrg. Dept., Trumpington St., Cambridge CB2 1PZ, UK  
Intl. J. Fatigue, 6 (4), pp 203-210 (Oct 1984), 9 figs, 33 refs

**KEY WORDS:** Fatigue life, Steel, Crack propagation

Fatigue crack growth rate and crack closure responses of BS4360 50B steel are determined for a service load history of a gas storage vessel. Crack propagation rates are independent of specimen thickness. Crack growth is successfully predicted by linear summation using the Paris law. No significant improvement is achieved by incorporating crack closure into the analysis. Choice of cycle counting technique also has an insignificant effect on the predicted fatigue life.

**85-1229**

**Sorting Out Hydraulic Fatigue - Pressure Ratings**

S.J. Skaistis

Vickers, Inc., Troy, MI

Mach. Des., 56 (24), pp 85-87 (Oct 25, 1984), 5 figs

**KEY WORDS:** Fatigue life, Hydraulic equipment

The NFPA fatigue-pressure rating standard has been in use for more than ten years. Although problems remain the standard is a reliable way to rate the fatigue strength of hydraulic components. Effective use of ratings requires knowledge of carrying out fatigue tests and of their significance.

**85-1230**

**Influence of Microstructure on the Cyclic Crack Growth in a Low-Alloy Steel**

J.C. Radon, J. Woodtli  
Swiss Federal Labs. for Materials Testing, Dubendorf, Switzerland  
Intl. J. Fatigue, 6 (4), pp 221-227 (Oct 1984), 19 figs, 11 refs

**KEY WORDS:** Fatigue tests, Crack propagation, Steel

Fatigue tests were performed on compact type and four point bend specimens of a low-alloy steel BS4360-50D in air at 30 Hz and at various stress ratios. The influence of microstructure on the fatigue crack propagation was studied. Region I of crack growth showed crystallographic facets. Two classes of secondary cracks were observed in Region II. Ductile tearing occurred in Region III. Dimple formation was also observed.

**85-1231**

**Repeatability of Gel Electrode Measurements of Fatigue Deformation in 6061-T6 Aluminium**

W.J. Baxter  
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Intl. J. Fatigue, 6 (4), pp 243-252 (Oct 1984), 18 figs, 9 refs

**KEY WORDS:** Fatigue tests, Aluminum

The gel electrode method was used to detect fatigue deformation in 6061-T6

aluminium. Measurements can be repeated to monitor distribution and accumulation of deformation at intervals during a fatigue test. Fatigue deformation is detected as early as 0.1% of the fatigue life. Charge flow measurements and gel electrode images show that the deformation accumulates at many sites during the early stage of fatigue life. About 50% of life clusters of sites of fatigue damage are well established. They provide a path for final fracture.

## EXPERIMENTATION

85-1232

### **Spectral Methods for the Euler Equations: Part I: Fourier Methods and Shock Capturing**

M.Y. Hussaini, D.A. Kopriva, M.D. Salas, T.A. Zang  
NASA Langley Res. Ctr., Hampton, VA  
AIAA J., **23** (1), pp 64-70 (Jan 1985), 8 figs, 1 table, 29 refs

**KEY WORDS:** Spectrum analysis, Fourier analysis

Spectral methods for compressible flow are introduced in relation to finite difference and finite element techniques within the framework of the method of weighted residuals. Current spectral collocation methods are put into historical context. Basic concepts of Fourier spectral collocation methods are provided. Filtering strategies for shock-capturing approaches are presented. Fourier shock-capturing techniques are evaluated. A one-dimensional, periodic astrophysical nozzle problem is used.

85-1233

### **Application of Modal Analysis to the Design of a Fan-Foundation System**

S.C. Ulm  
GE-CAE International, Milford, OH  
S/V, Sound Vib., **18** (12), pp 14-19 (Dec 1984), 10 figs, 3 refs

**KEY WORDS:** Modal analysis, Fans, Foundations, Structure-foundation interaction

A computer model of the system was built. Dynamics of the system were optimized to hasten on-line availability and minimize future maintenance problems. The project demonstrates the use of modal analysis in a production environment. Software commercially available to the engineering community is used.

85-1234

### **Theoretical Calculation of Coupled Vibrations of Coordinate Measuring Instrument (Systemtheoretische Berechnung der Kopplungsschwingungen von Koordinatenmessgeräten)**

E. Just, I. Triebel  
Technische Hochschule Ilmenau, German Dem. Rep.  
Feingerätetechnik, **33** (12), pp 548-550 (1984), 7 figs, 4 refs (In German)

**KEY WORDS:** Coupled response, Measuring instruments

Coupled vibrations of multi-body multi-degree-of-freedom systems are investigated. The equation of state, initial equation, equation of motion, and deflections are derived. They are used to calculate coordinate measuring instrumentation. The method and the program are also applicable for the analysis of other vibrators.

85-1235

### **Seismic Simulation at C-E**

K.H. Haslinger  
Combustion Engrg., Inc., Windsor, CT  
Test, **46** (5), pp 12-16 (Oct/Nov 1984), 80 figs, 5 refs

**KEY WORDS:** Test facilities, Nuclear power plants, Earthquake resistant structures

Combustion Engineering's (C-E) seismic simulation test facility has been upgraded. Objectives were: to eliminate undesirable table resonances, to triple the design overturning moment up to 600 in-kip, to boost table velocities up to 50 in./sec continuous, to meet high generic required re-

sponse spectra and to synthesize waveforms that meet the waveform stationarity concerns.

**85-1236**

**A Simple Interferometric Vibrometer Based on a Laser Doppler Velocimeter**

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B-1640 Rhode St. Genese, Belgium  
J. Phys., E: Sci. Instrum., **17** (11), pp 984-986 (Nov 1984), 4 figs, 7 refs

**KEY WORDS:** Vibration meters, Interferometric techniques, Lasers

A simple heterodyne speckle interferometer can be built by slightly modifying a classical laser Doppler velocimeter (LDV) for fluid flows applications. The random character of the speckle scattered by a rough surface is used. The statistical description of the measured signals is a function of the number of speckle grains collected by the photodetector. Three types of simple demodulators are proposed and demonstrated. LDV frequency counters can be used to process continuous frequency-modulated signals obtained in a speckle interferometer.

**85-1237**

**Impulse Loading Method for the Identification of Dynamic Parameters of Mechanical Systems**

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Inst. of Mechanics and Vibroacoustics,  
Krakow Technical University of Mining and Metallurgy, Krakow, Poland  
Strojnicki Casopis, **35** (5), pp 583-599 (1984), 15 figs, 2 tables, 13 refs

**KEY WORDS:** Mechanical systems, Natural frequency, Impact excitation

The impulse loading method consists of the excitation of vibration by a short impact and analysis of vibration range. The method is convenient but gives only approximate results. The approximation was evaluated by comparing results from theoretical cal-

culations with those of experimental studies by harmonic and impact excitation. The repeatability of the results obtained with the impulse loading method was also evaluated. The concurrence of results of both methods of measuring with respect of frequency and admittance module was examined.

**85-1238**

**A Two-Dimensional Force Transducer**

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J. Phys. E: Sci. Instrum., **17** (12), pp 1214-1219 (Dec 1984), 8 figs, 3 tables, 6 refs

**KEY WORDS:** Transducers, Force measurement

The two-dimensional force transducer is capable of measuring magnitude, direction, and position of a force acting in the plane of a transducer. The basic sensing method is strain gage bridges. The outputs are amplified and fed to a microcomputer for calculation of force characteristics. A working model confirmed the feasibility of the transducer. The latter was designed to measure quasi-static forces. Experiments were relatively successful. Further research is required to improve accuracy and capability of measuring dynamic forces.

**85-1239**

**New Instruments Speed Control System Design**

R.J. Van Woert

Hewlett-Packard Corp., Lake Stevens, WA  
Mach. Des., **56** (27), pp 109-113 (Nov 22, 1984), 6 figs

**KEY WORDS:** Signal processing techniques, Test instrumentation

The dynamic signal analyzer (DSA) can shorten the cycle of design, test, and analysis in control systems, electronics, and mechanical applications. A DSA combines the functions of several test instruments

and a computer into a single unit. By sampling and digitizing time waveforms, the microprocessor-based DSA can transform sampled information into useful information for time and frequency domain measurements.

**85-1240**

**A Modal Survey Test Facility for Shuttle Payloads**

N.W. Smith, A. Stroeve  
Ball Aerospace Systems Div., Boulder, CO  
S/V, Sound Vib., 18 (11), pp 20, 29-33 (Nov 1984), 11 figs, 4 tables, 7 refs

**KEY WORDS:** Experimental modal analysis, Test facilities, Space shuttles

A cost effective modal survey facility designed for shuttle payloads is discussed. Existing vibration test equipment is used to reduce the initial cost of the facility. A rigid shuttle bay simulating seismic fixture designed to hold shuttle payloads is described. A modal survey of the complete fixture is discussed. Use of the facility on a shuttle launched spacecraft called the Earth Radiation Budget Satellite (ERBS) is included. The success and shortcomings of the facility are discussed.

**85-1241**

**New Ways of Estimating Frequency Response Functions**

H. Vold, J. Crowley, G.T. Rocklin  
Structural Dynamics Res. Corp., Milford, OH  
S/V, Sound Vib., 18 (11), pp 34-38 (Nov 1984), 7 figs, 5 refs

**KEY WORDS:** Frequency response function

Method  $H_2$  improves estimation accuracy close to resonances.  $H_v$  employs a tensorial (geometric) approach for uniformly robust estimation. This article compares the performance of these methods over a range of excitation techniques and structure types. The effect of the estimation techniques on popular modal extraction methods is also presented.

## DYNAMIC TESTS

**85-1242**

**Dynamic Tensile Tests of Composite Materials Using a Split-Hopkinson Pressure Bar**

C.A. Ross, W.H. Cook, L.L. Wilson  
Univ. of Florida Graduate Engrg. Ctr., Eglin Air Force Base, FL  
Exptl. Tech., 8 (11), pp 30-33 (Nov 1984), 6 figs, 7 refs

**KEY WORDS:** Composite materials, Dynamic tests, Tensile strength, Hopkinson bar technique

Dynamic testing covers many tests and extends over a wide range of strain rates. It is important to define the load or strain rate associated with the type of dynamic test being conducted. This discussion is concerned with high-strain-rate tensile tests of composite materials in the strain-rate range of  $10^2 - 10^3/s$ .

**85-1243**

**Random Vibration Excites in All Axes**

L.R. Lee  
L. Lee Consultants Inc., Westport, CT  
Test, 46 (5), p 11 (Oct/Nov 1984), 1 fig

**KEY WORDS:** Vibration tests, Random vibration

All elements that compose the fixture and how they behave under vibration must be considered in design of a vibration fixture. Random vibration is a powerful screening tool in modern testing. At saturation of a specimen all parts are accelerating and decelerating at a rate different from the input acceleration except when that part is in anti-resonance. A poorly designed fixture has a resonance in any axis.

## MONITORING

**85-1244**

**Expert System for Machinery Fault Diagnosis**

R.G. Smiley

Entek Scientific Corp., Cincinnati, OH  
S/V, Sound Vib., **18** (9), pp 26-29 (Sept 1984), 8 figs, 2 tables

**KEY WORDS:** Monitoring techniques, Machinery

Effective machinery maintenance programs require management of many disciplines. Economics, machine dynamics, computerized data management, ferrospectroscopy, thermodynamics, and personnel management are a few examples. A modern maintenance program generally incorporates information from such sources to minimize and schedule downtimes.

**85-1245**

**Laser-Based Non-Destructive Testing Techniques for the Ultrasonic Characterization of Subsurface Flaws**

A.M. Aindow, R.J. Dewhurst, S.B. Palmer, C.B. Scruby  
Dept. of Appl. Physics, University of Hull, Hull, HU67RX, UK  
NDT Intl., **17** (6), pp 329-335 (Dec 1984), 8 figs, 13 refs

**KEY WORDS:** Failure detection, Nondestructive tests, Lasers, Acoustic emission

A pulsed Nd:YAG laser system was used to generate the ultrasonic source. An He-Ne laser interferometer detected subsequent surface displacements. The technique allows assessment of width and depth of flaws. Analysis of data shows that the method is suited to detection of flaws equal to or less than 4 mm below the surface of a sample. This region is difficult to inspect by conventional contact ultrasonic techniques.

**85-1246**

**Acoustic Emission: Some Problems, Tasks and Solutions**

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NDT Intl., **17** (6), pp 323-328 (Dec 1984), 6 figs, 15 refs

**KEY WORDS:** Acoustic emission, Fatigue life, Metals

Recent studies of acoustic emission (AE) in metal samples and structures undertaken at CNIITMASH are reviewed. General features of AE are discussed. Results from investigations include evaluation, sensitivity, AE signal models, AE during plastic deformation, and AE from fatigue cracks. Aspects of AE source classification and criteria for object rejection are considered.

**85-1247**

**The Use of Surface Scanning Waves to Detect Surface-Opening Cracks in Concrete**

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NDT Centre, AERE Harwell, Didcot, Oxon OX11 0RA, UK  
NDT Intl., **17** (5), pp 273-275 (Oct 1984), 4 figs, 3 refs

**KEY WORDS:** Concrete, Crack detection, Nondestructive tests

The use of ultrasonic surface waves to locate surface-opening cracks in concrete is described. The system works in transmit-receive and reflection modes. Laboratory results demonstrate the effectiveness of the system. Advantages and possible applications of the technique are discussed.

**85-1248**

**Efficient Machinery Screening for Improved On-Line Performance**

J.S. Mitchell  
Palomar Technology Intl., Inc., Carlsbad, CA  
S/V, Sound Vib., **18** (9), pp 16-25 (Sept 1984), 9 figs

**KEY WORDS:** Monitoring techniques, Machinery, Computer-aided techniques

Improving machinery availability and reducing maintenance costs can increase the profitability of any production operation. Simple, proven screening methods and microprocessor-based instrumentation technology are described. They can be used to

implement an efficient predictive maintenance system.

## ANALYSIS AND DESIGN

### ANALYTICAL METHODS

85-1249

**An Approximate Technique for the Analysis of Oscillations in Abruptly Nonlinear Systems**

M.A. Heidari

Ph.D. Thesis, Univ. of Southern California (1984)

**KEY WORDS:** Linearization methods, Non-linear systems

The new method introduces a weighting function into the averaging integral used in the familiar equivalent linearization technique. The main discussion is directed toward vibroimpact analysis of structural systems. Single and two degree-of freedom (SDOF) systems subjected to harmonic excitation are considered. The approach is extended to the computation of peak displacement of a nonlinear SDOF oscillator subjected to earthquake excitation.

85-1250

**Mixed Variational Principles for Some Non-Self-Adjoint Dynamical Systems**

L.Y. Bahar, H.G. Kwatny

Drexel Univ., Philadelphia, PA 19104

Mech. Res. Comm., 11 (4), pp 253-263 (July/Aug 1984), 16 refs

**KEY WORDS:** Variational methods      Lagrange equations

The bilinear Lagrangians have been generalized to dynamical systems with multiple degrees of freedom. Their variational formulation leads to governing equations of motion. Conversely, the construction of bilinear Lagrangians starts from the equa-

tions of motion and uses the methodology of the inverse problem of Lagrangian dynamics. These facets are the subject of the present investigation.

85-1251

**On the Non-Linear Beck's Problem with External Damping**

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Center for Applied Mathematics, Indiana Univ.-Purdue Univ. at Indianapolis, IN 46223

Intl. J. Nonlinear Mech., 12 (6), pp 497-505 (1984), 4 figs, 19 refs

**KEY WORDS:** Stability, Columns, External damping, Follower forces, Beck's theory

A nonlinear Beck's problem with external damping is analyzed for the first time. The problem exhibits a Hopf bifurcation. The character of this bifurcation is ascertained. Nonlinear stability is examined. Previously unanswered questions are addressed. Comments on the discontinuous nature of the undamped limit are given.

85-1252

**Analysis of Parametrically Excited Large Vibration Systems**

G. Schweitzer, F. Meyer

Inst. fuer Mechanik, Eidgenoessische Technische Hochschule, Zurich, Switzerland

177 pp (June 1984), AD-A143 283

**KEY WORDS:** Parametric excitation, Dynamic stability, Floquet theory, Perturbation theory, Numerical analysis

The stability of such systems can be characterized by stable and unstable regions in the plane of two significant system parameters epsilon and omega. The objective of this work is to reduce computer-time consumption by combining Floquet theory, perturbation analysis, and numerical methods. This analytical/numerical method provides effective procedures for the stability investigation of large parametrically excited vibration systems.

85-1253

**On Generalized Hopf Bifurcations**

K. Huseyin, A.S. Atadan

Univ. of Waterloo, Waterloo, Ontario, Canada

J. Dynam. Syst., Meas. Control, Trans. ASME, **106** (4), pp 327-334 (Dec 1984), 4 figs, 17 refs

**KEY WORDS:** Bifurcation theory, Harmonic balance method

Two degenerate Hopf bifurcation phenomena associated with autonomous lumped-parameter systems are explored using the intrinsic harmonic balancing method. It is assumed that the Hopf's transversality condition is violated and certain other conditions prevail. In one case the system exhibits a cusp shape bifurcation path. The second case is concerned with a tangential bifurcation phenomenon that need not be exhibited unless an additional condition is satisfied. This condition is obtained in the course of analysis. Results concerning bifurcating paths and limit cycles are given in general, explicit forms that should be useful in a variety of applications.

85-1254

**Dynamics and Control of General Linear Lumped-Parameter Systems**

M. Ahmadian

Ph.D. Thesis, State University of New York at Buffalo, 128 pp (1984), DA8426013

**KEY WORDS:** Lumped parameter method, Linear systems

The systems under consideration are divided into symmetric, symmetrizable, and asymmetric systems. Various phenomena related to vibrations, stability, and control of these classes of systems are explored systematically. Theorems concerning the basic properties and characteristic features of each class are formulated. The theorems have practical and theoretical value. The examples include only mechanical systems, but the general nature of formulation allows for application of the theory to problems in other areas.

85-1255

**Dynamic Interactions Between Cracks (Diffractions of SH Waves Which are Incident on Griffith Cracks in an Infinite Body)**

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Bull. JSME, **27** (234), pp 2605-2610 (Dec 1984), 3 figs, 15 refs

**KEY WORDS:** Boundary value problems, Cracked media, Wave diffraction

The transient dynamic boundary value problems of elastic bodies with cracks are formulated in forms of integral equations. Equations for anti-plane problems are worked out in detail. Numerical calculations are carried out. Variations of stress intensity factors with time are clarified for SH step-stress waves incident on one or two Griffith cracks in an infinite body.

**NUMERICAL METHODS**

85-1256

**Survey of Numerical Integration Procedures for Technical Vibration Problems (Übersicht über numerische Integrationsmethoden für technische Schwingungsprobleme)**

E. Gossmann, H. Waller

Ruhr-Universität Bochum, Arbeitsgruppe für numerisches Rechnen in der Mechanik und Simulationstechnik, Fed. Rep. Germany  
Forsch. Ingenieurwesen, **50** (5), pp 149-159 (1984), 10 figs, 13 refs (In German)

**KEY WORDS:** Numerical analysis, Time dependent excitation

Vibrations are excited by time-dependent loadings. To evaluate the time history of the response, it is necessary to integrate the differential equation of motion for a suitable simplified mechanical system. For linear systems an analytical solution is prepared for an integration method suited to digital computers. The properties of general numerical integration procedures are discussed. All time-dependent vibration problems, mainly nonlinear ones, can be

handled by these methods. Differences in integration procedures and selection of a suitable method are discussed.

methods linear to characteristic values for solution of this problem are discussed and tested by means of examples.

## PARAMETER IDENTIFICATION

85-1257

### Identification of Linear Structures

B. Wolf

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J. Dynam. Syst., Meas. Control, Trans. ASME, 106 (4), pp 300-304 (Dec 1984), 5 figs, 10 refs

**KEY WORDS:** System identification techniques, Linear systems, Viscous damping

Experimental frequency response data for a linear dynamic system is used to obtain system transfer functions. An easily implemented multi-degree-of-freedom technique is presented that is applicable to linear structures with moderate, non-proportional viscous damping. Experimental data at the resonant and antiresonant frequencies and high and low frequency data are sufficient to identify the system.

85-1258

### Identification of Mechanical Dynamic Systems by Means of Weight Function (Identifikation mechanischer dynamischer Systeme über die Gewichtsfunktion)

H.J. Hardtke

Technische Universität Dresden, Sektion Grundlagen des Maschinenwesens, Bereich Dynamik und Betriebsfestigkeit, German Dem. Rep.

Maschinenbautechnik, 33 (9), pp 407-411 (1984), 4 figs, 21 refs (In German)

**KEY WORDS:** System identification techniques

In the identification of mechanical systems from exciter and response functions the weight function plays a significant role. Several parametric and nonparametric

## OPTIMIZATION TECHNIQUES

85-1259

### Structural Optimization with Dynamic Behavior Constraints

W.C. Mills-Curran, L.A. Schmit

Sandia National Labs., Albuquerque, NM

AIAA J., 23 (1), pp 132-138 (Jan 1985), 9 figs, 5 tables, 21 refs

**KEY WORDS:** Optimization, Damped structures, Periodic excitation

The minimum weight optimum design of damped linear elastic structural systems is addressed. Structures are subjected to periodic loading. There are behavior constraints on maximum deflections and side constraints on design variables. Attention is focused on two impediments to an optimal solution: the time-dependent nature of the behavior constraints, and the severe nonconvexity of the design space caused by the dynamic response constraints. A solution method based on upper bound approximations for the behavior constraints and an innovative mathematical programming scheme for seeking the optimal frequency subspace is set forth. Numerical results for two test problems illustrate the effectiveness of the method.

## COMPUTER PROGRAMS

85-1260

### VIBRA-An Interactive Computer Program for Steady-State Vibration Response Analysis of Linear Damped Structures

L.M. Bowman

NASA Langley Res. Ctr., Hampton, VA

Rept. No. NASA-L-15771, NASA-TM-85789, USAAVSCOM-TR-84-B-1, 66 pp (July 1984), AD-A143-555

**KEY WORDS:** Computer programs, Periodic response, Damped structures, Linear systems

An undocumented vibration response analysis based on modal superposition was developed about 10 years ago. The analysis calculates the acceleration response at any selected point on a structure for specified vibratory loading. The purpose of this report is to document the improved version of VIBRA (Vibration Response Analysis) computer program. The theoretical background, program description, and application are presented along with user instructions and a sample interactive computer session.

**85-1261**

**DYNA3D User's Manual (Nonlinear Dynamic Analysis of Solids in Three Dimensions)**

J.O. Hallquist

Lawrence Livermore National Lab., CA

Rept. No. UCID-19592-Rev.1, 109 pp (Apr 1984),

DE84012828

**KEY WORDS:** Computer programs, Finite element technique

This report provides an updated user's manual for DYNA3D, an explicit three-dimensional finite element code for analyzing the large deformation dynamic response of inelastic solids. A contact-impact algorithm permits gaps and sliding along material interfaces. A specialization allows such interfaces to be rigidly tied to admit variable zoning without the need for transition regions. The equations-of-motion are integrated by the central difference method. The 15 material models and nine equations of state to cover a wide range of material behavior.

**85-1262**

**Structural Mechanics Software. 1979-October, 1982 (Citations from the NTIS Data Base)**

NTIS, Springfield, VA

251 pp (Sept 1984), PB84-874437

**KEY WORDS:** Computer programs, Bibliographies

This bibliography contains citations concerning the utilization of computer programs in structural analysis and design. Topics include applied and theoretical analyses of stress, vibration, deformation, and shear properties. Design optimization programs are listed. Citations pertaining to the NASTRAN program are excluded.

**85-1263**

**ADAMS - A Universal Program for the Analysis of Large Displacement Dynamics (ADAMS - Ein universelles Programm zur Berechnung der Dynamik grosser Bewegungen)**

M. Bartels, E. Fischer

Pappelweg 31, 3550 Marburg/Lahn

Automobiltech. Z., 86 (9), pp 369-376 (Sept 1984), 11 figs, 5 refs (In German)

**KEY WORDS:** Computer programs, Automobiles

ADAMS (automatic dynamic analysis of mechanical systems) is one of the most advanced computer programs in its field. This American program from Mechanical Dynamics, Inc., Ann Arbor, Michigan, and available in Europe through TEDAS, Marburg (Germany), is capable of analyzing two- and three-dimensional mechanical systems. One area of application has been the automotive industry. Included are kinematic, static, and dynamic analysis of suspension systems; total vehicle simulation for ride and handling; and dynamic effects in the powertrain. It is user-friendly.

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# ABSTRACT CATEGORIES

## MECHANICAL SYSTEMS

Rotating Machines  
Reciprocating Machines  
Power Transmission Systems  
Metal Working and Forming  
Isolation and Absorption  
Electromechanical Systems  
Optical Systems  
Materials Handling  
Equipment

## STRUCTURAL SYSTEMS

Bridges  
Buildings  
Towers  
Foundations  
Underground Structures  
Harbors and Dams  
Roads and Tracks  
Construction Equipment  
Pressure Vessels  
Power Plants  
Off-shore Structures

## VEHICLE SYSTEMS

Ground Vehicles  
Ships  
Aircraft  
Missiles and Spacecraft

## BIOLOGICAL SYSTEMS

Human  
Animal

## MECHANICAL COMPONENTS

Absorbers and Isolators  
Springs  
Tires and Wheels

Blades  
Bearings  
Belts  
Gears  
Clutches  
Couplings  
Fasteners  
Linkages  
Valves  
Seals  
Cams

## STRUCTURAL COMPONENTS

Strings and Ropes  
Cables  
Bars and Rods  
Beams  
Cylinders  
Columns  
Frames and Arches  
Membranes, Films, and Webs  
Panels  
Plates  
Shells  
Rings  
Pipes and Tubes  
Ducts  
Building Components

## ELECTRIC COMPONENTS

Controls (Switches,  
Circuit Breakers  
Motors  
Generators  
Transformers  
Relays  
Electronic Components

## DYNAMIC ENVIRONMENT

Acoustic Excitation  
Shock Excitation

Vibration Excitation  
Thermal Excitation

## MECHANICAL PROPERTIES

Damping  
Fatigue  
Elasticity and Plasticity  
Wave Propagation

## EXPERIMENTATION

Measurement and Analysis  
Dynamic Tests  
Scaling and Modeling  
Diagnostics  
Balancing  
Monitoring

## ANALYSIS AND DESIGN

Analogs and Analog  
Computation  
Analytical Methods  
Modeling Techniques  
Nonlinear Analysis  
Numerical Methods  
Statistical Methods  
Parameter Identification  
Mobility/Impedance Methods  
Optimization Techniques  
Design Techniques  
Computer Programs

## GENERAL TOPICS

Conference Proceedings  
Tutorials and Reviews  
Criteria, Standards, and  
Specifications  
Bibliographies  
Useful Applications

# CALENDAR

## JULY

**2-4 Ultrasonics International '85**, Kings College, London (Z. Novak, Ultrasonics, P.O. Box 63, Westbury House, Bury St., Guildford, Surrey GU2 5BH, England)

**11-13 International Compressor Engineering Conference**, Lafayette, IN (Purdue Univ., W. Lafayette, IN - (317) 494-2132)

## AUGUST

**4-8 International Computers in Engineering Conference and Exhibition [ASME]** Boston, MA (ASME)

**5-10 SAE West Coast International Meeting [SAE]** Portland, OR (SAE)

## SEPTEMBER

**2-7 International Gas Turbine Symposium and Exposition [Gas Turbine Div., ASME; Chinese Natl. Aero-Technology Import and Export Corp.; Chinese Soc. of Aeronautics and Astronautics]** Beijing, People's Rep. China (Intl. Gas Turbine Ctr., 4250 Perimeter Park South, Suite 108, Atlanta, GA 30341 - (404) 451-1905)

**9-11 19th Midwestern Mechanics Conference [Ohio State Univ.]** Columbus, OH (Dept. of Engrg. Mech., Ohio State Univ., 155 W. Woodruff Ave., Columbus, OH 43210 - (614) 422-2731)

**10-13 Design Automation Conference [ASME]** Cincinnati, OH (ASME)

**10-13 Failure Prevention and Reliability Conference [ASME]** Cincinnati, OH (ASME)

**10-13 Vibrations Conference [ASME]** Cincinnati, OH (ASME)

**16-20 DIAGNOSTICS - 85 [Technical Univ. Poznan / Polish Academy Sciences]**

Leszno, Poland (Diagnostics -85, Prof. C. Cempel, Tech. Univ. Poznan, Piotrowo 3, P.O. Box 5, 60-695 Poznan, Poland)

**18-20 INTER-NOISE '85 [Intl. Inst. Noise Control Engrg.]** Munich, Fed. Rep. Germany (E. Zwicker, Institut f. Elektroakustik, TU Munchen, Arcisstr. 21, 8000 Munchen 2, Fed. Rep. Germany)

## OCTOBER

**6-8 Diesel and Gas Engine Power Technical Conference [ASME]** Grove City, PA (ASME)

**8-10 Lubrication Conference [ASLE/-ASME]** Atlanta, GA (ASLE/ASME)

**8-11 Stapp Car Crash Conference [SAE]** Arlington, VA (SAE)

**14-17 Aerospace Congress and Exposition [SAE]** Los Angeles, CA (SAE)

**20-24 Power Generation Conference [ASME]** Milwaukee, WI (ASME)

**22-24 14th Turbomachinery Symposium [Turbomachinery Labs.]** Houston, TX (Dara Childs, Turbomachinery Labs., Dept. of Mech. Engrg., Texas A&M Univ., College Station, TX 77843)

**22-24 56th Shock and Vibration Symposium [Shock and Vibration Information Ctr., Washington, D.C.]** Monterey, CA (Dr. J. Gordan Showalter, Acting Director, SVIC, Naval Res. Lab., Code 5804, Washington, D.C. 20375-5000 - (202) 767-2220)

## NOVEMBER

**4-8 Acoustical Society of America, Fall Meeting [ASA]** Nashville, TN (ASA)

**11-14 Truck and Bus Meeting and Exposition [SAE]** South Bend, IN (SAE)

**17-22 American Society of Mechanical  
Engineers, Winter Annual Meeting [ASME]  
Miami Beach, FL (ASME)**

**DECEMBER**

**11-13 Western Design Engineering Show  
[ASME] Anaheim, CA (ASME)**

# **CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS**

<b>AHS</b>	American Helicopter Society 1325 18 St. N.W. Washington, D.C. 20036	<b>IMechE</b>	Institution of Mechanical Engineers 1 Birdcage Walk, Westminster London SW1, UK
<b>AIAA</b>	American Institute of Aeronautics and Astronautics 1633 Broadway New York, NY 10019	<b>IFTOMM</b>	International Federation for Theory of Machines and Mechanisms U.S. Council for TMM c/o Univ. Mass., Dept. ME Amherst, MA 01002
<b>ASA</b>	Acoustical Society of America 335 E. 45th St. New York, NY 10017	<b>INCE</b>	Institute of Noise Control Engineering P.O. Box 3206, Arlington Branch Poughkeepsie, NY 12603
<b>ASCE</b>	American Society of Civil Engineers United Engineering Center 345 E. 47th St. New York, NY 10017	<b>ISA</b>	Instrument Society of America 67 Alexander Dr. Research Triangle Pk., NC 27709
<b>ASLE</b>	American Society of Lubrication Engineers 838 Busse Highway Park Ridge, IL 60068	<b>SAE</b>	Society of Automotive Engineers 400 Commonwealth Dr. Warrendale, PA 15096
<b>ASME</b>	American Society of Mechanical Engineers United Engineering Center 345 E. 47th St. New York, NY 10017	<b>SEB</b>	Society of Environmental Engineers Owles Hall, Buntingford, Herts. SG9 9PL, England
<b>ASTM</b>	American Society for Testing and Materials 1916 Race St. Philadelphia, PA 19103	<b>SESA</b>	Society for Experimental Mechanics (formerly Society for Experimental Stress Analysis) 14 Fairfield Dr. Brookfield Center, CT 06805
<b>ICF</b>	International Congress on Fracture Tohoku University Sendai, Japan	<b>SNAME</b>	Society of Naval Architects and Marine Engineers 74 Trinity Pl. New York, NY 10006
<b>IEEE</b>	Institute of Electrical and Electronics Engineers United Engineering Center 345 E. 47th St. New York, NY 10017	<b>SPE</b>	Society of Petroleum Engineers 6200 N. Central Expressway Dallas, TX 75206
<b>IES</b>	Institute of Environmental Sciences 940 E. Northwest Highway Mt. Prospect, IL 60056	<b>SVIC</b>	Shock and Vibration Information Center Naval Research Laboratory Code 5804 Washington, D.C. 20375-5000